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ABSTRACT

This 2-year study, which took a multidisciplinary approach to the problem of discovering principles for designing effective multimedia instruction, focused on the effects on instructional effectiveness of the discourse structure of instructional materials and the coordination of multiple instructional media. The task domain was a logic box said to control an irrigation system. Fifteen different stimuli were prepared, each including an explanation of how the box works; each was shown to a group of approximately 25 California community college students. The stimuli were videotapes of a professional actor following a carefully prepared multimedia script involving use of verbal explanation, diagrams on a blackboard, and the box itself. The stimuli comprised two series, the first using a fully-crossed design with three binary independent variables, and the second exploring seven variants of a single explanation type. Separate objective tests were devised for each series, sharing several questions to permit cross-series comparisons. Analyses relied chiefly on 1- and 3-way ANOVAS, tests to evaluate between group differences, and correlations between individual items and total test scores. The major findings suggest that the choice of discourse type can strongly affect comprehension; comprehension can be improved by gestural coordination between visual and verbal material and use of suitable visual icons; both cognitive level and manipulation of the internal structure of discourse units have significant and systematic effects on comprehension; and inclusion of summaries, particularly initial summaries, seems to assist comprehension. Eight guidelines for media production are included, and scripts and test materials used in the experiment are appended. A reference list is also provided. (JB)

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OPTIMAL STRUCTURES FOR MULTIMEDIA INSTRUCTION

Final Report

July 1985

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This final report presents the results of a two-year study of the structure of multimedia instruction. The real-world problem that has inspired this research is how to design effective multimedia instructional materials. There is, of course, a vast body of information on learning and the bases of effective learning, but, there has been little research on the effects of the discourse structure of instructional materials or on the coordination of multiple instructional media. Also, technology has introduced new media, such as interactive computer graphics, as well as new possibilities for combining media in the instructional situation (e.g., using videodisc).

In designing instructional materials for such media, one should use theoretically motivated and experimentally verified principles for choosing among the many possible instructional structures and representations possible using the various media involved. This report presents research aimed at exploring some basic principles of this kind. The

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major findings include the following:

- Choice of discourse type can strongly affect comprehension; this is a new result that would not have been predicted by any current theory of instruction or comprehension.
- Gestural coordination between visual and verbal material can significantly help comprehension.
- Suitable visual icons can greatly aid comprehension, even when they are not coordinated with linguistic material.
- Cognitive level has a very significant and systematic effect on comprehension.
- Manipulation of the internal structure of discourse units has significant and systematic effects; in particular, the greater the level of structure violated, the greater seems to be its effect on comprehension. To discover this effect requires a relatively fine-grained theory of discourse structure.
- Inclusion of summaries, particularly initial summaries, seems to assist comprehension.

These results seem quite encouraging for a new research paradigm in such a complex area as multimedia instruction. Moreover, they suggest some interesting directions for further research. They also have specific implications for instructional design, as detailed in Sections 5.3 and 5.4, respectively.

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Optimal Structures for Multimedia Instruction: Final Report

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1 Introduction

This final report presents the results of a two-year study of the structure of multimedia instruction. The major findings include the following:

- Choice of discourse type can strongly affect comprehension; this is a new result that would not have been predicted by any current theory of instruction or comprehension.
- Gestural coordination between visual and verbal material can significantly help comprehension.
- Suitable visual icons can greatly aid comprehension, even when they are not coordinated with linguistic material.
- Cognitive level has a very significant and systematic effect on comprehension.
- Manipulation of the internal structure of discourse units has significant and systematic effects; in particular, the greater the level of structure violated, the greater seems to be its effect on comprehension. To discover this effect requires a relatively fine-grained theory of discourse structure.
- Inclusion of summaries, particularly initial summaries, seems to assist comprehension.

These results seem quite encouraging for a new research paradigm in such a complex area as multimedia instruction. Moreover, they suggest some interesting directions for further research. They also have specific implications for instructional design, as detailed in Sections 5.3 and 5.4, respectively.

1.1 The Problem

The real-world problem that has inspired this research is how to design effective multimedia instructional materials. There is, of course, a vast body of information on learning and the bases of effective learning (for example, see [Estes 78]). However, there has been little or no research on the effects of the discourse structure of instructional materials or the coordination of multiple instructional media. Also, new technology has introduced new media, such as interactive computer graphics, as well as new possibilities for combining media in the instructional situation (e.g., using videodisc). (See [Ong 82, Ong 81] for a discussion of the

history of profound changes imposed on educational systems by the introduction first of writing, and later, of printing.)

For conventional instructional media there are, if not general design principles, at least a body of experience and folk wisdom about how to proceed. But there is no such accumulated experience for the production of materials using video and computer technology. Furthermore, such media permit, and indeed almost require, much greater complexity of design than conventional media. Therefore, in designing such materials, one should use theoretically motivated and experimentally verified principles for choosing among the many possible instructional structures and representations possible using the various media involved. This report presents research aimed at exploring some basic principles of this kind.

1.2 Technical Approach

This study takes a multidisciplinary approach to the problem of discovering principles for designing multimedia instruction. The disciplines include experimental psychololgy, discourse analysis (the study of linguistic units larger than the sentence) and semiotics (the study of the general principles of sign systems, such as language, visual gesture, diagrams, and mixtures of these).

The experimental studies build on our prior naturalistic studies of the structure of explanation (see [Goguen & Linde 84]). In these prior studies, we devised an experimental task, built a demonstration device, and elicited explanations about its operation from experienced instructors (engineering professors at a local community college). These explanations were videotaped and analyzed to determine the range of explanation structures, use of diagrams, gestures, and the like in spontaneous instructional discourse. This body of information was then used in generating the hypotheses tested in subsequent phases of this study.

The task domain used in the experiments reported here was essentially the same as for the elicitation study: a logic box said to control an irrigation system (see Figure 5). Fifteen different stimuli were prepared, each including an explanation of how the box works; each was shown to a group of approximately 25 volunteer subjects, who were local community college students. The stimuli were videotapes of a professional actor following a carefully prepared multimedia script, involving use of verbal explanation, diagrams on a blackboard, and the box itself. The stimuli comprise two series, the first experimental series employs a fully-crossed design with three binary independent variables; the second explores seven variants of a single explanation type.

The variables in the first series were: Discourse Type (Pseudonarrative versus Reasoning), presence or absence of discourse Structure Marking; and presence or absence of Visual Deixis. All explanations in this series were at the Combinatorial cognitive level[1]; that is, the lights were directly keyed to switch patterns, rather than to the Boolean functions that generate those relations.

All explanations in the second series used reasoning discourse structure. Experimental manipulations were designed to explore effects on comprehension of: presence of initial summary, presence of final summary, presence of focus inconsistencies at the sentence level, presence of discourse unit boundary violations, presence of discourse section scrambling, and visual icon not coordinated with verbal discourse. All explanations in the second series were at the Boolean cognitive level; that is the Boolean relations between the lights and switches were explained (however, the uncoordinated icon represented the combinatorial level).

Separate objective tests were devised for each series, sharing several questions to permit cross-series comparisons. Scores on these questionnaires were used as the dependent measure. Analyses relied chiefly on 1- and 3-way ANOVAS, using t tests to evaluate between group differences; in addition, correlations between individual items and total test scores were used to determine the appropriateness of a summary dependent measure. A number of hypotheses were tested using these procedures, resulting in both the conclusions already summarized, and several practical recommendations.

2 Theoretical Background

This section discusses three theoretical systems underlying in this work: discourse analysis, cognitive level, and semiotics. It then introduces some experimental variables suggested by these theories.

2.1 Discourse Type

In this research, discourse analysis is used as a major tool for the generation of hypotheses, production of experimental material, and interpretation of results. Discourse analysis takes as data extended stretches of language occurring in a natural setting, in this case, instructional discourse. It then determines the discourse units present, and analyzes their formal structure. (For detailed discussion of the methodological basis of discourse analysis, see [Linde 81, Linde &

[1] See Section 2.2 for further discussion of cognitive levels.

Goguen 80]; for an example of the practical application of this method to context of commercial aviation communication see [Goguen & Linde 83].)

A **discourse unit** is a segment of spoken language, longer than a single sentence, with socially recognized initial and final boundaries, and a formally definable internal structure. A **discourse type** is a theory of the structure of a class of discourse units. Major discourse types that have been studied include:

- the narrative of personal experience [Labov 72],
- the pseudonarrative, e.g., spatial descriptions [Linde 74, Linde & Labov 75],
- small group planning [Linde & Goguen 78],
- the joke [Sacks 74] and
- reasoning [Weiner 79, Goguen, Weiner & Linde 83].

Analysis of the taped naturalistic explanation sessions showed that the major discourse units used in instructional discourse are reasoning, plans, and pseudonarrative. A discourse type provides a tree structure for its discourse units, breaking it down into subparts, which themselves may be further decomposed. These tree structures can be seen to result from the application of a sequence of transformations [Linde & Goguen 78, Goguen, Weiner & Linde 83, Goguen & Linde 84] representing the real-time effects of additions and modifications of the reasoning structure, as well as movements of the focus of attention. Thus the sequence of trees represents the individual or group process of the production of a discourse unit, and the final tree represents the finished unit. Each discourse type has distinctive node types which characterize it, as well as some node types such as AND which seem to be common to all discourse types.

Discourse structures may be indicated in spontaneous speech either by explicit discourse structure markers, such as **first**, **next**, and **finally** which indicate current position, or implicitly by the semantics of the component sentences. Below is a pseudonarrative stimulus passage, as used in the current experiments, with its structure markers italicized:

> *So to begin*, **we have this controller with two switches and four lights** *and* **we have to learn how to operate it.** *Now* **let's make sure that there really are just four possible ways to set these two switches. We'll** *start* **with the** *first* **setting, which has both switches up.** *Then* **we go to the** *second* **setting, which has both switches down.** *Then* **we go to the** *third* **setting, which has the first switch up and the second switch down.** *Finally*, **we go to the** *fourth* **setting, which has the first switch down and the second switch up.** *And that's all* **the settings that there are.** *So* **this fertilizer controller can only select among four mixtures of chemicals to add to the water.**

Such discourse structure markers indicate the organization of the discourse unit; they mark the beginnings of new subtrees, and hence correspond to a movement of focus of attention first up the structure tree, and then back down to the root of a new subtree. Thus, in the example above, the **so** in the final sentence indicates a movement of the focus of attention back to the top node of the discourse. Markers of this type are called "POP" markers.

The following subsections briefly discuss reasoning and pseudonarrative discourse structure, then consider summaries as parts of these discourse types, and finally introduce the notion of focus. All of these linguistic concepts are involved in the experimental design of this study.

2.1.1 Reasoning

Reasoning is a discourse type in which the speaker states a proposition, and then gives reasons for believing its truth. The basic constructor of reasoning is STATEMENT/REASON, which connects two subtrees in a relation of support, so that the material subordinated by the REASON node provides logical support for the material subordinated by the STATEMENT node, as shown in Figure 1.

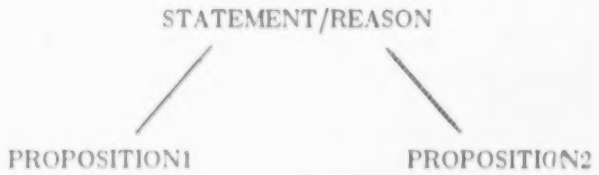

Figure 1: The Basic Constructor of Reasoning

A STATEMENT/REASON node may embed other nodes, such as AND, OR and IF/THEN, and either it or its subordinates may also embed further subordinate STATEMENT/REASON nodes. Thus, discourse units of this type may have rather deep and complex tree structures.

Note that this definition picks out a specific discourse type, which serves the social function of explanation. This social function of explanation may be accomplished by many discourse types including reasoning, narrative, pseudonarrative, and planning. Previous research has studied reasoning, using as data accounts of income tax decisions, accounts of career choice, and accounts of the possible effects of certain political decisions [Weiner 79, Goguen, Weiner & Linde 83].

The following is a typical example of reasoning at the Boolean cognitive level, from our elicitation studies; the structure of this discourse is shown in Figure 2.

> **You can get a little more complicated. Like you can think about what the individual lights do. One of the interesting things with this one,**

it doesn't depend upon this switch at all. Like to see [inaudible] Switch Two. So if it's off when Switch Two is down, it's on when Switch Two is up, independent of what happens with Switch One. So, Switch Two controls light C. You know, let's see, what's another one? I think D says that the two switches are the same ... so if they're both down or both up, D is on, but, if they're different, D is off. I think A, if I remember right, A is, is th-, no B is that they're both down. Uh, in any other position B is off. And then there's a more complicated one. What was that? If A's, A says that it's not anything other than One up or Two down, then it's on. Then that's off. It gets a little bit more complicated when you explain it that way.

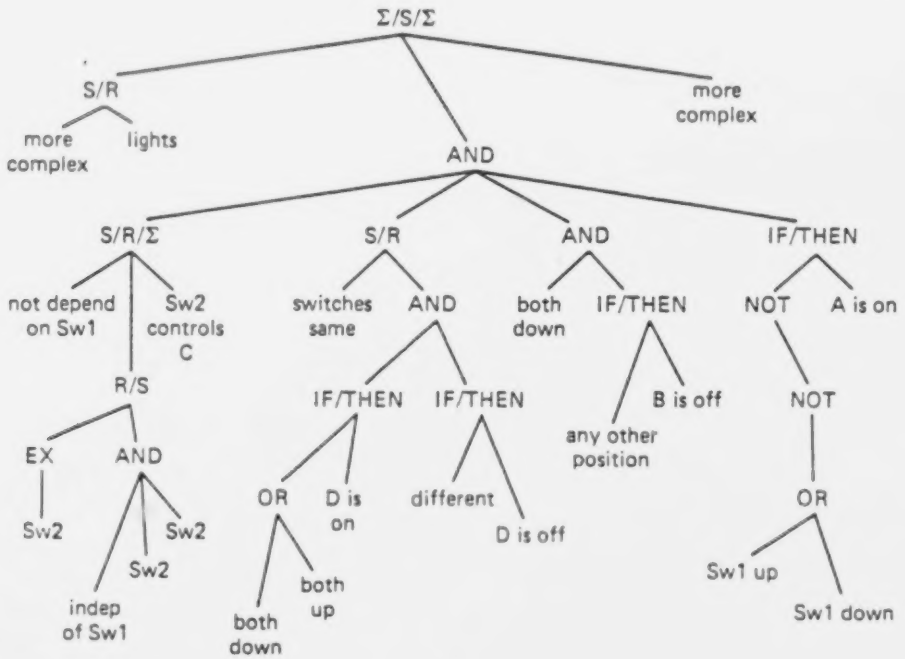

Figure 2: Structure Tree for a Reasoning Unit

Notice in Figure 2 that two nodes of this structure have summary branches; the top (root) node actually has two summary branches, one given before the body of the reasoning structure and the other given after. The body of this reasoning structure consists of an AND that subordinates four other reasoning structures, one for each light on the box. A summary is given after the first of these. It is interesting to notice that the order in which the lights are considered is not their physical order on the box (which would be A, B, C, D, going left to right, see Figure 5); rather, the lights are discussed in order of increasing *logical complexity* (which is C, D, B, A). It is also of interest to note that some of the REASONs are actual demonstrations of what happens when the switches are in a certain position. In one of these, for the C branch, the demonstration is given first, and then three conclusions are drawn from it, subordinated to an AND node.

2.1.2 Pseudonarrative

Pseudonarrative is a discourse type which imposes a temporal structure on an essentially non-temporal topic domain. It has some but not all of the characteristics of the **narrative** [Labov 72, Linde & Labov 75, Polanyi 85]. Formally, pseudonarrative consists of an optional initial summary, or "abstract", a sequence of past tense main clauses describing actions, and an optional final summary, or "coda". Like narrative, pseudonarrative relies on the **narrative presupposition**, the rule of interpretation which states that the order of main clauses is to be taken as the order of the events which they describe. The difference is that the past tense main clauses of the narrative refer to actions which are to be understood as actually having happened, while those of the pseudonarrative refers to hypothetical, potential, or habitual actions.

The basic constructor of pseudonarrative is SEQUENCE, which connects two or more actions in a relation of temporal sequence (see Figure 3).

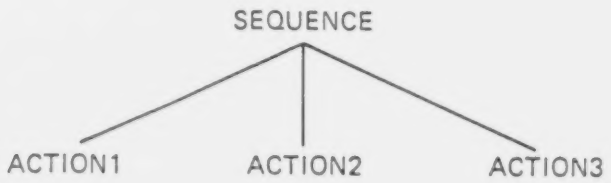

Figure 3: Basic Constructor of Pseudonarrative

The narrative presupposition gives the interpretation of Figure 3 in which the temporal order is ACTION1 precedes ACTION2 which precedes ACTION3. Since SEQUENCE nodes do not self-embed, this constructor produces broad trees, with little depth. However, some depth may be provided by the embedding IF/THEN, AND and OR nodes within ACTION nodes. Below is a pseudonarrative from the elicitation data:

> **We'll go through it again slowly. O.K. In one position of these two switches, where One is up and Two is down, all these lights are off. We take Switch One and move it to its other position, three of the lights come on. We reverse this combination and make them both go up, we got again three of the lights are on but a different three lights. And, if we move em till both down, again, we got three lights on but these two lights are changed over.**

The structure tree for this pseudonarrative is given in Figure 4. Note the narrative structure imposed by the use of the personal pronoun **we** and the active verbs **go, take, move, make**, indicating actions by human participants rather than states of the device.

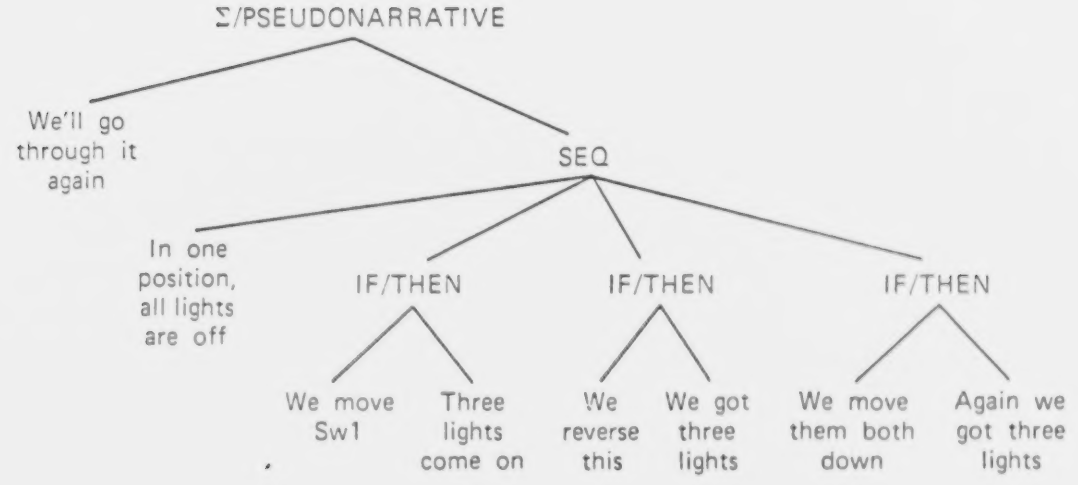

Figure 4: Structure Tree for a Pseudonarrative

Pseudonarrative has previously been studied in the domain of apartment layout descriptions [Linde 74, Linde & Labov 75]. In this domain the speakers commonly used pseudonarrative structure to convert spatial organization to temporal organization. It was found that speakers produced such temporally organized discourse units more frequently than any other way of encoding the information of the apartment layout. Also, psuedonarratives contained fewer errors than any other discourse type, suggesting that pseudonarrative is a relatively simple discourse type for speakers to produce.

2.1.3 Summaries

One important variable on discourse structure is the presence or absence of summaries. A summary is a section of a discourse unit which gives either the main points of that unit, or a guide to the overall structure of the discourse unit, or both. Summaries have been found to be a part of narrative structure. [Labov 72] calls initial summaries "abstracts" and final summaries "codas". Abstracts, at the beginning of narratives, serve to indicate either the narrative's relation to the preceding discourse, or the way in which the hearer(s) should understand and react to the narrative. Codas, found at the end of narratives, serve either to reiterate the main point, or to bring the discourse back to the present moment.

Summaries are found in both reasoning and pseudonarrative, and may have either initial or final placement. The naturalistic data elicited in the first part of this study contained a few examples of medial placement, but all were produced by just one speaker, who was judged (by

independent criteria) to be outstandingly disorganized and unskillful. Figures 2 and 4 show summaries in reasoning and psuedonarrative structures, respectively.

Summaries as an integral part of discourse structure have not previously been studied experimentally. However, their role can be seen as being in some ways comparable to the role of **elaborations** as discussed by [Reder *et al.* 84, Reder 80], defined as

> ... pieces of information that support, clarify, or further specify the main points (or gist) of a text.

2.1.4 Focus

Another experimental variable depends on the concept of linguistic **focus**. Focus is a property of sentences. The focus of a sentence is that information in the sentence which is presupposed to be known to the hearer, and to be present to the hearer's attention. It is usually, but not always, the grammatical subject of the sentence. In the sentences below, the items in focus are indicated in italics.

The lights **depend on the position of the switches.**

The switches, **you just have to memorize.**

Focus was experimentally manipulated in this study, since rapid alternation of foci in adjacent sentences appears to produce passages that are confusing for a reader or hearer.

2.2 Cognitive Level

Explanations of the logic box can be formulated at a number of different cognitive levels, including the following:

1. **Behavioral**: a simple, unanalyzed description which matches a pattern of lights to a corresponding switch position.
2. **Combinatorial**: treats the possible patterns of lights as an aggregate. This might be displayed in a table, like a truth table, showing the relation of switch positions and lights. (A possible addition at this level of description explains that only four combinations of switch position are possible, by simple multiplication of two switches times two switch positions.)
3. **Logical**: indicates the Boolean functions of the switch positions represented by each light, using AND, OR, IF, etc.
4. **Electronic**: uses a circuit diagram or similar device to indicate how the relation between switch position and light patterns is accomplished.
5. **Physical**: uses the principles of physics and chemistry that underly the level of electronics.

The naturalistic elicitation experiments contain examples of Levels 1 through 3; we did not attempt to elicit explanations at other levels.

Our experiments show (see Section 4.3) that cognitive level, as we operationalized it in this study, has a strong effect on comprehension. However, the notion of a scale or hierarchy of conceptual levels raises the problem of scaling. For given tasks, it is often possible to produce an intuitive or *ad hoc* scale, based solely on the structure of the task rather than on any motivated theory of possible cognitive levels. While theoretically motivated studies of cognitive level are common in the investigation of children's cognitive development, this research has not been extended to adult learning.

A number of researchers have found that they require cognitive level as a variable in the study of explanations in various subject domains. For example, [Kieras 82] distinguishes among knowledge of what a device is for, how to operate it, and how it works. The first two levels of description of our task correspond to varying degrees of knowledge of the first type: how to operate the device. The third, fourth, and fifth levels correspond to varying degrees of knowledge of how the device works. Note that a description at any of these five levels may function as an explanation, depending on the purpose of the description and the existing level of understanding of the audience. Similarly, in a study of Navy instruction manuals, [Stevens & Steinberg 81] provide a typology of explanations which begins at the behavioral level and proceeds to more abstract forms of explanation. (It is not possible to make an exact match between the higher levels of their taxonomy and the taxonomy given above, since ours is a simple, non-branching tree structure, while theirs is a matrix of four two-way distinctions. However, there does seem to be some correspondence in terms of degree of abstraction.) These studies, like the current study, point to the importance of cognitive level as a variable in the study of comprehension. A great deal of further work on adult learning is necessary to provide a theoretically based understanding of possible cognitive levels and their effects.

2.3 Semiotics

Semiotics is a natural theoretical framework for the investigation of multimedia instruction, since it attempts to provide a general theory of all sign systems and their relations, including spoken and written language, gesture, diagram, etc. [Goguen & Linde 84] provides a general formal theory for describing sign systems, providing a rich and suggestive vocabulary for formulating experimental hypotheses. Appendix I summarizes aspects of this general theory. The following discusses some semiotic concepts which were used in formulating the hypotheses of this study.

2.3.1 Cross-media Reference and Visual Deixis

Multimedia instruction typically involves mixed sign systems, that is, its signs occur in a mixture of media (eg. visual and verbal, or verbal and gestural). Under such circumstances, it is important to coordinate events happening in different media. A phenomenon of particular importance for this kind of coordination is the use of a sign in one medium to indicate a sign in another; we call this **cross-media reference**. It is more pervasive than might at first be supposed. In our experiments, we found that instructors often point at things they have written or drawn on the board. The material on the board, in turn, may refer to properties or states of the physical logic box. Moreover, an instructor's spoken language often refers to aspects of the box or to material on the board.

One example of cross-media reference in the experimental domain is a reference to some aspect of a diagram, which itself refers to some aspect of the states of the box, as in

The second line shows what happens when both of the switches are down.

For a more complex example, an instructor in one of our elicitation sessions, on discovering that the box was now behaving in a way that seemed inconsistent with its previous behavior, pointed at a table on the blackboard and said

So it should have been, C on.

Here both **it** and the gesture refer to a row of the table, which in turn refers to a state of the box. (This reference had been previously established through a combination of spoken language and actually operating the box.) It might have been difficult or impossible to resolve the referent of **it** without the gesture.

Cross-media reference is often used in natural language for **emphasis**, that is, to point out or emphasize certain words. In written language, choice of type font is generally considered a completely independent medium from that of language. Therefore, choice of font can be, and often is, used for emphasis. Typical font choices for this purpose are ALL CAPS, **bold**, and *italics*. The relevance of a systematic study of cross-media reference to computer-based instruction is evident: one would like to know the optimal ways to use emphasis in an instructional context. For example, one might put parts of a text (in a window on a screen) in reverse contrast; or one might let it flash; or put it in a different color or a different size, or a different font; or some combination of the above. Similar consideration apply to graphics, animations, icons, sound effects, and computer-generated speech. One must decide what to emphasize, and how to emphasize it, in order to hold together an ongoing stream of information in a mixed media system. Too much emphasis, or too many different kinds of emphasis, will only produce confusion. These theses should also apply to more traditional media, such as overhead projections and videotape.

The most important kind of cross-media reference in this investigation is **visual deixis**, defined as the use of gesture to refer to some aspect of the visual world in order to connect it with some element of concurrent spoken or written language. Note that this restricted definition excludes many instances of pointing or visual reference when there is no language actually present. The definition also excludes situations in which a speaker points to some aspect of the visual scene which is unconnected to his ongoing talk (for example, gesturing to point out the passage of an acquaintance during the course of an unrelated conversation). Visual deixis as defined here has not previously been studied; previous studies of gesture have concentrated on independent gestures which are not keyed to features of the concurrently present physical world [Efron 41, McNeill 79].

2.3.2 Levels of Discourse Structure and Sign Systems

The semiotic theory summarized in Appendix I suggests the importance for comprehension of hierarchical organization in complex sign systems. In natural language, every level (except the lowest level of phonetics) is composed of sequences of units from the next lower level; the hierarchy is in fact a multilevel whole/part hierarchy. These general considerations (e.g., see the discussion of "semiotic morphism" in Appendix I) suggest that it should be more important to preserve the higher level structures than the lower level structures. Reflecting their relative importance, linguistic entities that mark the boundaries of higher level structures tend to be less subtle, more obvious.

2.4 Experimental Variables Suggested by These Theories

The theories discussed above provide a foundation for identifying a number of key variables used in hypotheses about effective multimedia instruction. These variables include:

1. **Discourse type**. This refers to the linguistic structure of the explanation; the two discourse types we studied are Pseudonarrative and Reasoning.
2. **Structure Markers**. Linguistic markers of internal discourse structure may or may not be employed.
3. **Visual Deixis**. Gestures can connect visual and verbal media. We manipulated occurrence of pointing to some aspect of the logic box, or the diagram used to explain it.
4. **Cognitive level**. The specific levels we explored are Combinatorial and Boolean.
5. **Summaries**. Initial and/or final summaries may be present or absent in a given explanation. (We did not examine effects of medial summaries.)
6. **Within-Sentence Focus Consistency**. The focus (on switches or lights) may be consistent or inconsistent within parallel structures within sentences.
7. **Discourse Unit Boundary Violations**. Related information may or may not be continued across the boundaries of discourse subunits.

8. **Discourse Unit Scrambling**. The ordering of discourse units may be permuted or not.
9. **Consistency of Visual Icon**. The diagram may be coordinated or uncoordinated with the verbal explanation that accompanies it.

3 Method

This section discusses the experimental task, experiment design, choice of subjects, production of test stimuli, and dependent measures.

3.1 The Experimental Task

The substantive task utilized in this research involves a "logic box" (see Figure 5). This box has two switches and four lights, each light being a logical function of the positions of the two switches. Both in the study of elicited explanations, and in the experimental study, the box was taken to be the controller for an irrigation system, which is able to deliver different mixtures of water and chemicals depending upon the setting of its switches.

3.2 Hypotheses and Experimental Design

The hypotheses were grouped into two series: one a fully-crossed design on three binary independent variables, and the other a set of six individual variables. The first series, the Combinatorial Series, consists of explanations presented at the Combinatorial level, accompanied by a referentially coordinated visual representation. The second series, the Boolean Series, consists of explanations presented at the Boolean level, all but one of which is accompanied by a referentially coordinated visual representation. In the Boolean level explanations, the box was explained to be programmable; that is, its current relation between lights and switches was taken to be only one of many possible. In the Combinatorial level explanations, the box was explained as non-programmable; that is the relation between lights and switches was taken to be fixed.

3.2.1 Explanations at the Combinatorial Level: Research Design

Described below are eight conditions representing explanations at the Combinatorial level. These eight conditions comprise a fully-crossed design with three binary independent variables which varies Discourse Type (DT, Pseudonarrative versus Reasoning), Visual Deixis (VD, present or absent) and verbal Discourse Structure Marking (SM, present or absent), as shown in Figure 9. The texts for these stimulus conditions are given in Appendix II. All these explanations assume that the configuration of the box is fixed, rather than programmable, and all employed the diagram shown in Figure 12.

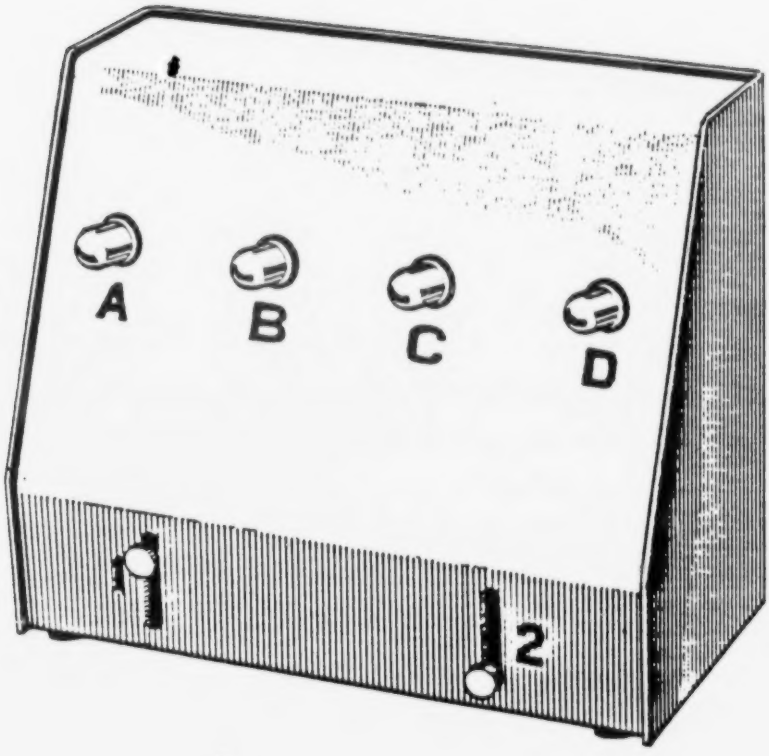

Figure 5: The Logic Box

3.2.2 Explanations at the Boolean Level: Research Design

The second series, at the Boolean cognitive level, has as its main discourse unit an explanation which has Reasoning structure rather than Pseudonarrative structure. The overall strcuture of this stimulus consists of a plan structure whose goal is stated in the initial task description:

Today we're going to learn how to operate this device

. The plan consists of a number of discourse units embedded under the plan node, including explanation structures, a description, and initial and final summaries. The top-level discourse structure of this stimulus is shown in Figure 6.

A "standard" explanation with this structure, and six variants of it were employed:

B1: Standard Boolean explanation, including initial and final summaries, a coordinated visual icon, and internally consistent subunits;

B2: No Initial summary;[2]

[2]When summaries were omitted, appropriate filler material was included to hold length approxiamtely constant.

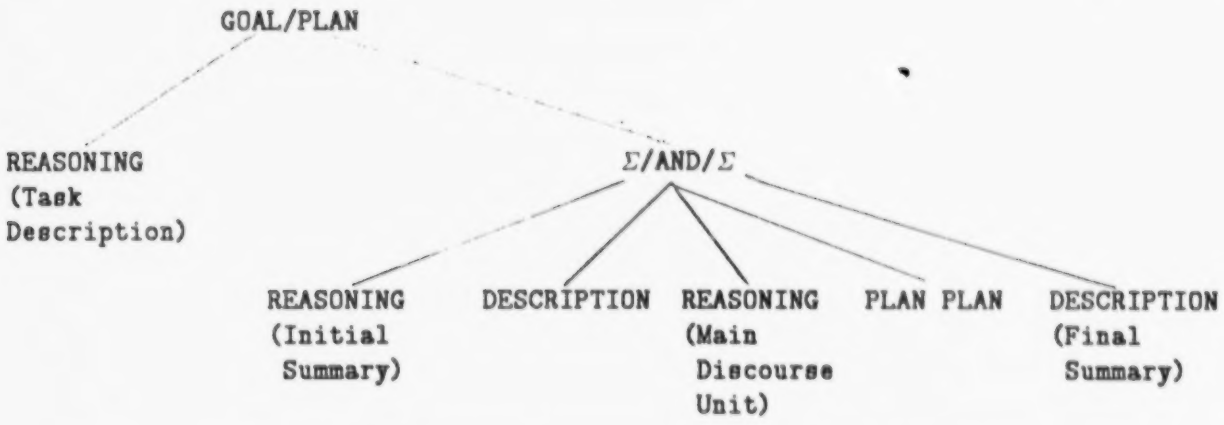

Figure 6: Top-level Structure of Boolean Level Stimulus

B3: No Final summary;

B4: Sentential focus inconsistencies;

B5: Discourse subunit boundary violations;

B6: Scrambled ordering of discourse subunits;

B7: Use of diagram not coordinated with the cognitive level of the verbal portion of the stimulus. (A combinatorial rather than a Boolean level diagram was used.)

We may note that B-5 was constructed from B-1 by permuting clauses across discourse unit boundaries, and then modifying intersentiential connectives to make the language smoother. B-6 was constructed from B-1 by permuting entire component discourse units.

The texts for these stimulus conditions are given in Appendix II. All these explanations assume that the configuration of the box is programmable.

3.3 Subjects

The experimental subjects were students at Foothill College, a local community college. Subjects were volunteers, chosen to have no college background in mathematics, logic, or computer science, and to be native speakers of English. They received $10 for participating. Bout 25 subjects per condition were tested.

3.4 Stimulus Production

The explanations described above were videotaped. A professional actor was used to ensure word-perfect delivery, as well as consistency of delivery, gesture, and timing across conditions. The actor partially memorized and partially read from scripts (projected onto the wall behind

the camera), since the perfect delivery of scripts which differ only slightly is very difficult. In order to reduce variations of the Visual Deixis variable, the actor used little or no gesture or movement other than those specified by the script. This led to a somewhat stiff delivery, which was noted by some of the subjects.

The explanations were filmed using a single stationary video camera. A stationary camera, with no change of camera angle or focal length, was used to avoid introducing the additional form of deixis which would be imposed by camera work. Wherever possible, segments repeated across conditions were filmed separately and edited in. In order to facilitate such editing, the scripts were divided into short scenes, and the actor walked off and then back on camera between these scenes.

3.5 Dependent Measures

Following the video-taped explanation of how logic boxes work, a paper-and-pencil test was administered by the experimenter. This was an objective test, with 12 items for the Combinatorial Series and 16 items for the Boolean Series. The tests have 7 items in common to enable cross-series comparisons. Students were permitted to take notes during the explanation, and to use these notes during the test, since our pilot tests showed that forbidding the use of notes produced extremely low scores with very little variance. These tests are reproduced in Appendix III.

4 Analytic Procedures and Results

This section summarizes the statistical results from this research, along with the analytical procedures that produced them and some discussion of their meaning. Section 5 gives a more complete interpretation of the results. Recall that the general structure of the experiments involves two series of stimuli, hereafter called the C or Combinatorial Series and the B or Boolean Series. Subsections below discuss general issues, present the procedures and results for the C Series data, and then for the B Series and cross-series data.

4.1 General Considerations

This subsection discusses level of significance, gives an overveiw of the C and B datasets, and then considers questionnaire item choice.

4.1.1 Levels of Significance

This project is an initial study in the largely unexplored field of multi-media explanation structure, using a new research method with new questionnaires as dependent measures, and based upon relatively novel insights from linguistics and semiotics. Hence, it should be regarded as paradigmatic and exploratory. We regard a result as "significant" if its obtained probability level is less than or equal to .05, and as "marginally significant if between .05 and .10; results with a probability level less than or equal to .01 will be called "very significant." In most cases, the obtained probability value is also given, so that the reader can independently judge the significance of the results. Two types of statistical test are employed: F tests for analyses of variance, and t tests for between-group comparisons. Unless otherwise indicated (e.g., in testing directional hypotheses) two-tailed tests are used.

4.1.2 Choice of Questionnaire Items

The C Series questionnaire has 12 items[3], the B Series has 16 items, and these two instruments have 7 items in common. Since none of these items had previously been used in experimental studies, it would have been desirable to do prior item- and scale-reliability studies; unfortunately this was impractical within the limits of the present project. However, we computed the correlation of each item with questionnaire score totals for each stimulus condition (in its series), and also across all stimuli (in its series), in order to determine the extent to which each question was contributing useful information to the analysis. The worst item that we found, item 14 in the B Series, showed low or negative correlation with total scores in 3 stimulus conditions; it had a .11 average correlation with total scores across the B Series, attaining a reasonably high r value in some conditions. Since analytic results item 14 differed very little from those that included item 14, its exclusion did not seem warranted. Consequently, we used all items in computing the scores. Tables of correlations are given in Figures 7 and 8.

4.2 Combinatorial Series Results

The C Series experiments studied effects of three 2-level independent variables, Discourse Type, Visual Deixis, and Structure Marking. The means and standard deviations for test scores obtained in the resulting conditions are given in Figure 9.

Combinatorial explanation data were analyzed using the SAS statistical package 3-way analysis

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[3]Item 5 of the C Series questionnaire was excluded because it was administered in an inconsistent manner; otherwise, there would have been 13 items, as given in Appendix III.1.

	Condition								mean
Question	C1	C2	C3	C4	C5	C6	C7	C8	r
1	.80	.50	.54	.51	.54	.26	.61	.47	.53
2	.62	.42	.84	.65	.34	.68	.51	.56	.58
3	.61	.0	.60	.45	.26	.20	.41	.27	.35
4	.47	-.01	.26	.36	.34	.34	.72	.33	.35
5	.36	.19	.50	.33	.37	.25	.65	.46	.39
6	.68	.47	.66	.51	.30	.42	.69	.40	.52
7	.29	.69	.41	.55	.43	.34	.61	.53	.48
9	.69	.69	.67	.45	.48	.38	.40	.49	.53
10	.39	.58	.55	.27	.43	.73	.52	.58	.51
11	.75	.21	.41	.63	.51	.30	.19	.61	.45
12	.20	.96	.42	.34	.66	.59	.43	.18	.47
13	.47	.37	.31	.59	.32	.16	.59	.13	.37
14	.47	.37	.21	.33	.46	.28	.41	.44	.37
mean r	.52	.42	.49	.46	.42	.38	.52	.42	.45
n	27	20	25	24	30	31	24	28	

Figure 7: Correlations between C Series Questionnaire Items and Total Scores, by Condition

	Condition							mean
Question	B1	B2	B3	B4	B5	B6	B7	r
1	.34	-.18	.41	.47	.32	.20	.32	.27
2	.38	.37	-.01	.57	.36	.15	.50	.33
3	.16	.35	.29	.59	.06	.32	-.04	.25
4	.30	.69	.19	.33	.15	.48	.27	.34
5	.42	.19	.37	.34	.34	.18	.02	.27
6	.43	.40	.29	.22	.42	.40	.09	.32
7	.28	.21	.08	.29	.09	.26	.30	.22
9	.42	.38	.19	.41	.68	.36	.35	.40
10	.18	.12	.39	.23	.36	.07	.36	.24
11	.04	.07	-.18	.16	.46	.48	.32	.19
12	.50	.36	.51	.17	.75	.53	.53	.48
13	.18	.26	.21	-.22	.42	.38	.002	.18
14	.33	.01	-.24	.29	.08	.25	.02	.11
15	.27	.32	.60	-.009	.19	.07	.30	.25
16	-.02	.38	.48	-.003	.29	.25	.50	.27
17	.33	.40	.34	.37	.48	.64	.30	.41
mean r	.27	.25	.23	.25	.32	.30	.24	.27
n	25	23	21	22	26	25	21	

Figure 8: Correlations between B Series Questionnaire Items and Total Scores, by Condition

of variance program (ANOVA). Total score on the 12-item C Series questionnaire as dependent measure. Our hypothesis was that each variable would significantly enhance comprehension

		Structure Marking		No Structure Marking	
		VD	No VD	VD	No VD
Pseudonarrative	$\bar{x}$	9.68	7.63	8.26	8.85
	sd	2.30	2.50	2.86	1.81
	n	25	24	27	20
Reasoning	$\bar{x}$	7.88	7.73	7.96	7.26
	sd	2.89	2.46	2.26	2.22
	n	25	30	27	31

Figure 9: Combinatorial Series Descriptive Statistics

scores. The overall model tested achieves a value of F=3.19 (df=4,204 with p=.0144). Main effects from two independent variables were observed. Discourse Type yields a highly significant effect on comprehension (F=7.00, with df=1,208 and p=.0088), subjects in the pseudonarrative condition scoring systematically higher than those in the reasoning condition. Presence of Visual Deixis has a marginally positive influence on dependent variable values (F=3.67, with df=1,208 and p=.057). The third independent variable, Sturcture Marking, does not significantly affect comprehension test outcomes. Finally, none of the interaction terms in the model is significant.

What this means is that the largest single effect on comprehension of explanations is from Discourse Type, with Pseudonarrative being very significantly better than Reasoning for our experimental task. Visual Deixis also has a positive effect on the dependent measure. The third most significant is the interaction between Visual Deixis and Structure Marking. Structure Marking is not significant, but contributes to the VD*SM interaction, which is more significant than the SM main effect. This indicates that Structure Marking has complex effects, and is not simply additive.

Pairwise comparison between subject groups' comprehension scores using Student's t test helps to clarify the situation. One immediate result is that the most effective condition is Pseudonarrative with Visual Deixis and Structure Marking, the condition in which all factors hypothesized to facilitate comprehension are present (1-tailed t tests show this to be significant for all conditions except Pseudonarrative with Visual Deixis but without Structure Marking). Similarly, the least effective condition is Reasoning without Visual Deixis and without Structure Marking, in which all hypothetically facilitating factors are absent. This seems reasonable.

The hypothesis that the mean of Pseudonarrative with Visual Deixis and Structure Marking is greater than the mean of Pseudonarrative with Visual Deixis but without Structure Marking,

has t=1.96, which is (1-tailed) significant; i.e., in Pseudonarrative with Visual Deixis, Structure Marking facilitates comprehension. On the other hand, we obtain a t value 1.83 for the hypothesis that the mean of Pseudonarrative without Visual Deixis and without Structure Marking is greater than the mean of Pseudonarrative without Visual Deixis but with Structure Marking. This is (1-tailed) significant; i.e., in Pseudonarrative without Visual Deixis, adding Structure Marking inhibits comprehension. This helps explain why Structure Marking does not show a main effect, but instead appears in an interaction term.

The results for Visual Deixis lean in the same directions, but the interactions are less significant. The hypothesis that the mean of Pseudonarrative without Visual Deixis and without Structure Marking is greater than the mean of Pseudonarrative with Visual Deixis but without Structure Marking says that in Pseudonarrative without Structure Marking, adding Visual Deixis might make things worse (its t=.81 is definitely not significant). In contrast, the hypothesis that the mean of Pseudonarrative with Visual Deixis and with Structure Marking is greater than the mean of Pseudonarrative without Visual Deixis but with Structure Marking says that in Pseudonarrative with Structure Marking, adding Visual Deixis definitely helps (its t=2.99 is very significant). Thus, it is reasonable that Visual Deixis should have a main effect.

4.3 Boolean Series Results

The B Series consists of 7 individual stimuli, described with their means and standard deviations in Figure 10.

Description	Stim	n	mean	sd
Standard Boolean Reasoning	B1	25	7.56	2.18
Initial Summary Replaced by Filler	B2	23	6.61	2.06
Final Summary Replaced by Filler	B3	21	7.05	1.86
Focus Inconsistency	B4	22	8.68	1.99
Discourse Unit Boundary Violations	B5	26	8.12	2.66
Scrambled Scenes	B6	25	7.48	2.43
Uncoordinated Diagram	B7	21	9.10	1.95

Figure 10: Boolean Series Descriptive Statistics

The seven Boolean Series stimuli, all of which employ Reasoning discourse structure at the Boolean cognitive level, were arranged into a variety of patterns and then examined using total score on the 16 item B Series questionnaire as dependent measure with t tests and 1-way ANOVAs. The means and standard deviations for these 7 stimuli are given in Figure 10. The two most evident and significant results are as follows: First, the condition which has initial

summary replaced by filler is the least effective condition; this means that among the manipulations studied here, the strongest effect is the omission of the initial summary. Second, the condition using a diagram at the Combinatorial rather than the Boolean level is the best stimulus; this is (2-tailed) significant for all stimuli except Sentential Focus Inconsistencies and Discourse subunit boundary violations. As discussed in Section 5, this result demonstrates the importance of relevantly iconic graphics for effective instruction.

We tested for the effect of cognitive level with a 1-way 3-level ANOVA, using data from both the Combinatorial and Boolean Series, using as the dependent measure the common items in the questionnaires for the two series. The specific hypothesis is that combinatorial level reasoning structure is more effective than boolean level reasoning structure using a combinatorial diagram, which is more effective than boolean level reasoning structure using a Boolean diagram. This result very significant ($F=13.18$, $df=2,68$ with $p=.0001$). We conclude that the combinatorial level is much more effective for this task, and that even introducing it in a diagram without coordinating it with the discourse is helpful.

In order to test whether manipulations of summaries or of structural boundary violations had more effect, a 1-way 2-level ANOVA was used to compare two groups of stimuli: the stimuli involving deformations of discourse structure at various levels of structure, and those involving replacement of initial and final summaries. The hypothesis is that replacement of a summary has a greater effect on comprehension. This comparison yielded $F=8.46$ ($df=1,162$ with $p=.0044$), which is very significant.

A further hypothesis on the role of summaries is that having both initial and final summary is best, and having a relevant initial summary is more helpful than having a relavant final summary. To test this, a 1-way 3-level ANOVA was used to compare the mean of the standard Boolean level stimulus having inital and final summaries with the mean of the stimuli with Initial Summary replaced by filler and Final Summary replaced by filler. This result is not significant. However, analysis of variance is not the best way to reveal ordering among conditions. On the other hand, our initial theoretical framework would not have justified a directional hypothesis in advnace. (Primacy effects literature would predict suppression of the initial summary would have more impairing effects while recency literature might predict lower comprehension when the final summary is suppressed.) Consequently we made pairwise comparisons between the conditions using t statistics. In this case, the Boolean level stimulus with initial and final summary is slightly more effective than than the stimulus having initial summary replaced by a filler. This result is marginally significant using a 1-tailed t test ($t=1.55$).

Looking at the set of stimuli involving discourse unit boundary violations, the means shows the following ordering: the stimulus with Focus Inconsistency is more effective than the one with Discourse Unit Boundary Violations, which is more effective than the one with Scrambled Scenes. Thus, larger the scope of the discourse structure boundaries violated, the greater is the effect. Once again, a 1-way 3-level ANOVA does not show this pattern as significant. However a comparison of Focus Inconsistency with Scrambled Scenes is significant (1-tailed t=1.83), which adds to the suggestive evidence for this finding. Moreover, this "Breadth of Scope Hypothesis" is consistent with the earlier result that summaries have more drastic effects. Summaries may be thought of as structure markings as representing the largest possible scope, since they mark the beginning and ending of reasoning structures, like opening and closing parentheses for an expression. (note: earlier version of this section is file called results.mss

5 Discussion and Conclusions

This section interprets the results presented in the previous section; this yields some suggestions for future research and some recommendations for the practical production of multimedia instructional material.

5.1 Combinatorial Level

We begin with a discussion of the results of the statistical tests on data from the Combinatorial Series, in which the patterns of lights are explained as the result of the patterns of switch positions.

5.1.1 Effect of Discourse Type

The strongest finding is that discourse type has an important effect on comprehension. Of the possible discourse types, we tested pseudonarrative and reasoning. These were the two discourse types most frequently found in our elicitations of naturalistic explanations, and therefore, are frequently represented in classroom instruction. Pseudonarrative was found to be much more effective for the subject matter and trial instrument used in this study.

This is an entirely new finding. While previous research on instruction has investigated many variables both at a micro-level (e.g., frequency index, effect of sensical versus nonsensical stimuli, forward and backward transfer, primacy and recency effects, etc.) and at a macro-level (e.g., behavioral modelling, prior set, conformity to expectation, etc.) the effect of discourse type has not been considered. This finding is important because it shows that even if cognitive level, length, and information content, which are known to affect comprehension, are held constant, a strong difference can still be produced by choice of discourse organization. The

immediate practical value of this finding is to suggest pseudonarrative as a preferred organization for instructional discourse, particularly with novices. This conclusion should be tested, however, for generalizability with other explanations. The finding also suggests the potential value of much more extensive research on the effects on comprehension of a wide range of discourse types, and of variations of structures within discourse types.

There are a number of observations to be made about the effect of pseudonarrative. In order to understand why pseudonarrative facilitates comprehension more than reasoning, we may look first at the basic constructors of these discourse types. As mentioned in Section 2.1.2, the basic construtor of pseudonarrative is SEQUENCE, which connects two or more actions in a relation of temporal order. Since SEQUENCE nodes do not self-embed, this constructor tends to produce broad trees. In contrast, the basic constructor of reasoning is STATEMENT/REASON, connecting a statement about the state of the world with a reason for believing it. STATEMENT/REASON nodes may embed other constructor nodes in complex ways, including other STATEMENT/REASON nodes, so that trees of considerable depth are possible. As [Yngve 60] has shown, excessive tree depth can produce considerable difficulties in language processing (although note that his findings are at the sentence level rather than the discourse level).

It might be argued that the fundamental difference between pseudonarrative and reasoning lies not in discourse structure, but rather in the fact that pseudonarrative involves the actions of persons, and is hence more interesting and involving than reasoning, which focuses on objects and events. This can be investigated by studying the distribution of sentential subjects in the experimental stimuli used in these experiments. In fact, in the stimuli we employed, both pseudonarrative and reasoning employ both types of sentential subjects (see Figure 11). Although pseudonarrative has more personal subjects, the distribution of differences is not significant (using the ξ^2 statistic). This suggests that discourse structure rather than type of sentential subject is responsible for the observed differences in comprehension. It would be interesting to explore this issue more fully by keeping subject types constant and varying discourse structure, and *vice versa*.

	Personal Subjects	Impersonal Subjects
Pseudonarrative	18	13
Reasoning	6	11

Figure 11: Sentential Subject Types in Pseudonarrative and Reasoning Explanations

Other research has also found pseudonarrative a preferred discourse type. [Linde 74] found that

96% of speakers gave a pseudonarrative descriptions of apartment layouts; the only alternative found was map-structured descriptions. Further, the pseudonarrative descriptions contained far fewer speech errors and false starts than the map descriptions. This is confirming evidence, from the domain of production rather than perception, that pseudonarrative is better for certain tasks.

Pseudonarrative structure is essentially the same as the structure of oral narrative. Oral narrative is known to be one of the most basic forms of discourse organization. It is among the first discourse types that children develop. (Only response pairs such as question-answer and greeting-greeting precede it.) Moreover, narrative serves as the model for a wide variety of discourse types such as pseudonarrative, hypothetical narrative, task directions, route directions, etc. Thus it should not be surprising that pseudonarrative is often more effective than other althernatives for discourse organization.

5.1.2 Effect of Visual Deixis

Recall that Visual Deixis is defined as the use of gesture to refer to some aspect of the visual world. In these experiments, such reference is generally either to the logic box itself, or to the diagram on the board. A 3-way ANOVA on C Series scores found that Visual Deixis has a marginally significant effect on comprehension, and is the second most important component of a significant model. Moreover, t tests showed that Visual Deixis has a very significant facilitating effect in Pseudonarrative when Structure Marking is already present. However, t tests showed no significant effects for Visual Deixis in Reasoning. This may be because gesture traditionally forms an integral and expected part of the Narrative discourse type, which is the prototype for Pseudonarrative, whereas gesture is less important for the more abstract Reasoning discourse type. The question of the role of visual deixis relative to different discourse types clearly requires more research.

5.1.3 Effect of Structure Marking

Even though the 3-way ANOVA did not find a significant main effect for Structure Marking, t tests show that it plays a significant but complex role. In Pseudonarrative, Structure Marking has a significant facilitating effect when Visual Deixis was already present, but has a significant negative effect in the absence of Visual Deixis. In Reasoning, Structure Marking showed no significant effects. The difference in these cases may be explained by the nature of discourse structure in the two discourse types. Pseudonarrative structure (see Section 2.1.2) is simpler than Reasoning structure, so that cues to the structure may be more confusing if they occur in unnatural forms, such as Structure Marking without Visual Deixis.

It is a somewhat puzzling result that Pseudonarrative without Visual Deixis and with Structure Marking is not more effective than Reasoning without Visual Deixis and with Structure Marking, or than Reasoning without Visual Deixis and without Structure Marking. One would expect among stimuli not having Visual Deixis but having Structure Marking, that changing for Reasoning to Pseudonarrative would yield a significant improvement in comprehension, since Discourse Type has the strongest facilitating effect. But these two means are not significantly different. Moreover, Pseudonarrative wihtout Visual Deixis and with Structure marking does not differ significantly from Reasoning without Visual Deixis and without Structure Marking, wihch is the least effective stimulus in this series. One possible explanation is that subjects find spoken Pseudonarrtive without Visual Deixis and with Structure Marking very strange, since it is a discourse type which is based on spoken Narrative, a very familiar and interactive discourse type in which gesture may be an integral and expected component. It is interesting to note that for Pseudonarrative, having either Visual Deixis or Structure Marking alone is less effective than having neither.

5.2 Boolean Level

We now discuss the results of experiments at the Boolean level, the level which attempts to convey the Boolean functions of the switch positions which the lights represent.

5.2.1 Effect of Diagram Structure

The manipulation at the Boolean level which showed the strongest effect was varying the diagram on the blackboard. The standard diagram, used with six of the seven Boolean stimuli, consisted of equations corresponding directly to the script spoken by the instructor. The diagram used in the seventh version, shown in Figure 12, is not coordinateded with the script, since it uses an **"X"** to indicate that a given light is on for a given switch setting, and this use of **"X"** is not explained at all in the discourse, which is about equations.

Sw1	Sw2	C	~C	Y	B	Z	D	A
Up	Up	X		X		X	X	X
Dn	Dn		X		X		X	X
Up	Dn		X			X		
Dn	Up	X				X		X

Figure 12: Uncoordinated Diagram Used with Boolean Level Explanations

For an example of how this diagram was used, as the instructor says

C equals switch 2

he points to its first column.

We had expected that this (rather drastic) lack of integration would produce comprehension problems. In fact, the opposite was true. This may be explained by the fact that even though the diagram is not coordinated with the script, it is in fact closer to the form of many of the questions than the equations are. Thus, for a question like

> **Can you get fertilized water consisting of the mixture A, C, D of chemicals?**

it is possible to obtain the answer directly from a single row of the diagram. In constrast, to obtain an answer using the equations would require considering three separate equations.

This result indicates the need for further research on chart and diagram structure. Although there has been some research, particularly on how to assess the quality of graphs (see [Koslyn *et al.* 83] for a review), the field is just beginning. We know that a good icon can be immensely valuable, but we do not yet know, except in very local instances, how to create one for a particular purpose. Some suggestions for how to advance the state of the art based on the results of the present research, are given in Section 5.5.

5.2.2 Cognitive Level Comparisons

To explore the effect of cognitive level on comprehension, we can compare the standard Reasoning stimuli from the two series, using the total score on the items common to the two questionnaires as the dependent measure. As predicted, a Combinatorial level explanation produces far superior comprehension than the Boolean level, for this task. Actually, more than this is true. The intermediate case, of Boolean level reasoning with a Combinatorial level icon, yields scores between those of the pure Boolean and Combinatorial stimuli; the 3-level ANOVA showed a strong main effect for explanatory condition.

The Boolean level stimulus appears to be too complex, introducing too much difficult material in a short presentation. Should an explanation at this level be necessary for some task, it should probably be longer than the one used in this experiment, which was controlled to have equal length across stimuli. Alternatively, Boolean explanations might be appropriate only for learners who are cognitively already familiar with the form of Boolean operations. (The domain-specificity of cognitive complexity , for instance, suggests this hypothesis.)

This result underlines the need to develop a theory of cognitive levels (as discussed in Section 2.2). Although we have found cognitive level to be an important variable for this task, this result can not be extended to other content areas until a general theory of cognitive level is available.

5.2.3 Cross-Level Discourse Structure Permutations

Conditions B4, B5, and B6 can be used to test the effect of deformations of discourse structure at increasing levels of structure. Stimulus B4 changes focus within and between adjacent sentences. That is, one clause (or sentence) may have as its focus the lights, while the next has has its focus the switches of the logic box. B5 has sentences or main clauses in scrambled order within a discourse subunit, but preserves the order of subunits. B6 has its discourse subunits in scrambled order, but scrambled so that no concepts are used before they are introduced. Mean scores show that the greater the unit of structure over which the deformations are performed, the harder the resulting stimulus is to comprehend. That is, change of focus at the sentential level produces better comprehension than scrambled sentences within a discourse unit, which in turn produces better comprehension than scrambled discourse sub-units. This is predicted by our theory of semiotic levels. (The difference between the first and third, is significant, but the differences from the second are not.)

An unexplained finding is that the three stimuli involving discourse structure permutations have mean scores equal to or better than the reference condition, that is, the stimulus which is in the normal order at all semiotic levels. At present, we have no explanation for this result; further research is required to clarify it. As previously mentioned, the first piece of research would be to repeat the administration of the reference condition, to determine whether some anomaly either in the subjects or the conditions of administration led to unexpectedly poor results. (Such replication would be relatively easy, since the videotaped stimulus is immediately useable.)

5.2.4 Effect of Summaries

The facilitating effect of summaries was studied in the Boolean Series. The means for the stimuli which had filler material in place of the initial and the final summary were lower than the means for the stimulus having both initial and final summaries; this is the expected result. The difference between the means for the initial and reference cases was marginally significant. We conclude that the experiment should be repeated, with a 2-way fully-crossed design.

It is part of general folk wisdom about effective speaking and writing that summaries are important. However, to our knowledge, previous research has not considered summaries as part of the discourse structure of the experimental stimuli. Rather, in many experiments, elaborations, priming questions or other materials were presented before the text proper began, sometimes with a considerable time delay. This means that they comprise a new discourse unit, not an integral part of the discourse unit being studied. Elaborations are similar to summaries

in that they are intended to give the readers or hearers information which helps them understand the text [Reder 80]. However, summaries are defined both in terms of the type of information they contain and as a structural unit within a given discourse type, while elaborations are defined only in terms of the the type of information they contain.

The study of the effects on comprehension of the component parts of a text is in itself very important, since it directly impacts the design of instructional materials. In spite of the difference in approach, there are some similarities between this body of research and the results of the present study. For example, the literature on elaborations shows effects similar to the the result that initial summaries are more effective than final summaries. This suggests that initial summaries may in fact have a priming effect in suggesting to subjects what to listen for.

5.2.5 Results Counter to Hypotheses

There are several results in the Boolean Series that were contrary to our *a priori* hypotheses, and that still seem somewhat puzzling.

1. Boolean level explanation with Combinatorial diagram was the most effective stimulus. We had originally thought that the inconsistency between the visual icon and the explanation would be hard to understand. But in fact, the icon was very close to what the questionnaire actually asked; one might well say "a picture is worth a thousand words," at least if it is an icon that is well-suited to the task.
2. We had postulated that the reference stimulus, Boolean explanation with Boolean level diagram, would be the most effective. However, two of the boundary violating stimuli, namely Focus Inconsistency and Discourse Unit Boundary Violations, seemed to actually *improve* comprehension over the reference stimulus, (although this difference was not significant). This result is counter-intuitive, and indicates a need for further research, in particular, to repeat the administration of the reference stimulus. It was, in fact, the first stimulus administered by an inexperienced researcher, and it seems possible that the conditions of administration may be responsible for the puzzling results.

5.3 Suggestions for Further Research

The results reported here, although very encouraging for an initial exploration into new territory, are in many ways incomplete. In particular, the hyptheses discussed in the current report form a relatively small subset of the much larger set generated by our conceptual framework, many others of which also appear to be promising candidates for empirical research. In addition, we have identified, and indicated earlier in this report, a number of experiments that should be refined and repeated.

Taking a somewhat broader perspective, we believe that the initial (partial) success of this program suggests a somewhat radical approach to computer graphics paralleling the structures found in successful natural multimedia interaction: a hierarchically structured icon having a rich system of indices into and out of the task domain, with clearly marked boundaries. In our experiments, the diagram used in the Combinatorial series is such an icon; as noted above, its structure corresponds closely to that of the tasks required by the test questions. I would be possible to makes the rows, columns, and cells in such an icon "mouse sensitive," so that interesting classes of tasks could be performed simply with graphical manipulations. The success of the "Visicalc" class of programs can be understood in this light. The currently popular use of icons in menus is very crude by comparison with such an approach, which we believe could be very valuable to explore further.

5.4 Recommendations for Practical Multimedia Instruction Production

In addition to suggesting various bits of further research, our results can be pulled together to suggest a set of practical guidelines for producing multimedia instructional packages:

- Carefully specify the task;
- Construct a "discourse plan" which details a correspondence between the task structure and the discourse structure;
- Provide a rich and relevant visual icon for the task;
- In the design of a visual icon, if tradeoffs are necessary, model the task, not the talk;
- Use pseudonarrative, if possible;
- Mark discourse boundaries clearly and explicitly;
- Provide initial and final summaries;
- Chose the appropriate cognitive level (even though cognitive level is a poorly defined theoretical concept, it can be a useful guideline in practice).

I. Semiotics

This appendix formulates precise notions of "sign system" (inspired by the thought of Charles Sanders Peirce) and of "semiotic morphism," which is a translation from signs in one system to signs (i.e., representations) in another. It also considers what makes some translations better than others. This supports a generative approach, in which optimal mulitmedia are generated logical representations (which Peirce would have called "interpretants"). A precise and formal approach is needed as a basis for computer programs to embody our theories, and is also helpful in particular by suggesting hypotheses to be tested.

These ideas should be applicable to many aspects of instruction as well as to other areas of communication. Some instances include generating appropriate explanations, determining good representations ("icons") for computer graphics, measuring the quality of analogies, and choosing good names for files in a directory. There is a very large literature that is relevant to problems like these. However, all studies that we know are restricted to a particular sign system (such as natural language) and/or a particular semantic domain, or else lack the precision of the theoretical model that we will present. Some recent research, however, is fairly close to ours in spirit. In particular, the problems of analogs and file names mentioned above have been studied by [Gentner 83] and [Carroll 82] respectively, who reach conclusions compatible with ours; specifically, they emphasize the importance of structure as opposed to content. However, their theoretical frameworks lack the hierarchical levels and constructor functions which enrich ours.

A good deal of [Peirce 65]'s work on the nature of signs is directly relevant to the study of multimedia instruction. For example, Peirce divided signs into icons, symbols and indices, according to the manner in which they signify. Peirce defines an **icon** as a "sign which refers to the Object that it denotes merely by virtue of characters of its own," "such as lead-pencil streak as representing a geometrical line." In contrast, a sign x is an **index** for an object y if x and y are regularly connected, in the sense "that always or usually when there is an x, there is also a y in some more or less exactly specifiable spatiotemporal relation to the x in question" [Alston 67]. "Such, for instance, is a piece of mould with a bullet-hole in it as sign of a shot" [Peirce 65]. In this example, the spatio-temporal relation is a causal one, and hence is quite generally applicable. However, there are also indices which function only in specified and restricted spatio-temporal contexts; examples include proper names, social security numbers and football player numbers. Finally, Peirce defines a **symbol** as a "sign which is constituted a sign merely or mainly by the fact that it is used and understood as such."

The notion of sign system used in this work (formally summarized in Definition 1 below) is inspired by Peirce's study of semiotics; it will be seen that most of our discussion concerns the structure of complex signs. Some formalization of the structure of a *system* of related signs is needed in order to study what makes one representation of a given sign better than another. This is because it is necessary to consider how to represent related (but significantly different) signs to avoid confusion and ambiguity; it is also necessary to consider what attributes of signs should be given priority in constructing their representations.

In all but the simplest sign systems, individual signs are organized into complex signs; for example, sentences are made of words. This is a fundamental strategy for rendering the complexity of non-trivial communication more manageable. One may iterate this strategy, by regarding complex signs at one level of analysis as individual signs at a higher level, and then forming complex signs from these as well, which leads to a multilevel hierarchy of sign structure. For example, linguistics recognizes the following levels: phonological (the sounds of a given language); morphological (the smallest repeated compounds of phonemes with a stable meaning); lexical (words); syntactic (phrases and sentences); and discourse (multisentential units). It is important to note that this is a "whole/part" hierarchy, in which items at each level are composed from components from the next lower level.

The whole/part hierarchical organization of complex signs requires that signs be considered not only individually but in their context. The immediate context of a sign consists of those other signs that surround it, in space and/or time, and that together with it form a complex sign at the next higher level. In numerous linguistic studies, it has been found that the context and speaker of a given sentence in a story are at least as important for determining its meaning as are the words that comprise it. (For an extreme example, the sentence "Yes" can mean almost anything when given an appropriate context.) Generalizing this, we may say that it is more useful to view meaning as being produced "top-down" rather than "bottom-up." (An example of the utilitiy of this view is found in artificial intelligence research, where contextual cues have been found to be essential in recognizing and disambiguating signs; this has particularly been true for speech understanding and machine vision projects.)

An important aspect is the particular **medium** in which a sign is expressed. Some media are sensory, e.g., visual, auditory, and kinesic representations. In addition, there are many important examples of mental sign activity, such as inferring a proposition from one or more others. Signs may involve more than one medium; for example, a telephone conversation involves the auditory medium, while a television program involves an audio-visual mix. The

signs of any given system have some particular mixture of media in which they are expressed. For our purposes, it is more convenient to regard a mixture of media as a single mixed medium, called the **medium** of the sign system; we may also call such a sign system **mixed**.

A very large number of different signs may be possible in a given mixed medium; and it may also be possible to organize these signs (or subsets of them) in a wide variety of different ways. Within a given mixed medium, a specific choice of signs and way of organizing them may characterize a particular sign system (of course other factors may also be involved.) Thus, a sign that is meaningful in one sign system may not be in another, even though they involve the same medium. For example, different alphabets (such as Roman, Greek and Cyrillic) involve different letters, although a given form for a letter may be used in more than one alphabet.

We now consider the structure of signs at a given level of the whole/part hierarchy of levels. Some of this discussion may be familiar from formalisms used in linguistics, but our purpose here is to develop an approach that is applicable to any sign system whatever. It is important to note that signs at level n are constructed from signs at level n-1 (and other signs at level n that are already so constructed). A given sign system admits only a certain limited number of ways to put parts together at a given level n; we will refer to these as its **constructors** at level n. In general, there is a classification scheme for the signs at a given level (e.g., the parts of speech are such a scheme for the syntactic level of a natural language system), and the constructors at that level can be seen as *rules* for combining signs of these various **classes** to get a new sign of another class. A familiar special case is that of context-free grammars.

Three additions to this basic scheme seem useful; there may well be others that we have not discovered. First, a given constructor (or rule) may have, in addition to its formal arguments, some number of **parameters**. For example, consider a graphic sign, say a cat, to be displayed on a graphics terminal; its parameters might be its size, and the location of its upper-lefthand corner; depending on their values, the cat may have a different size and location, but still be recognizably the same cat.

The second addition is that there may be a **priority ordering** on constructor functions. Under such an ordering, there may be a **primary constructor**, which has greater priority than any other constructor; there may also be one or more **secondary** constructors, each having less priority than the primary constructor and greater priority than any non-primary and non-secondary constructor, with none of these having priority over any other; similarly, there may be one or more **tertiary** constructors, and so on. This formulation yields a *partial*

ordering rather than a total ordering, since given two distinct constructors r1 and r2, it is not necessary that either one has priority over the other. For example, the reasoning discourse type [Goguen, Weiner & Linde 83] has a primary constructor, AND, which conjoins a number of reasons for the same statement[4]. Unfortunately, there has not yet been any experimental work on this subject, which would be an interesting extension of the work done for the present project.

The third addition is that of **context conditions**[5] on rules. These are conditions (i.e., predicates) that limit the applicability of a rule to certain particular contexts, namely those where the predicate is true. Context conditions often express constraints that arise as a result of structure at higher levels of the hierarchy, and are a feature of many recent grammatical formalisms [Kaplan & Bresnan 82], [Wasow *et al.* 82].

Many aspects of this approach to the structure of signs are present or implicit in Peirce, but as far as we can tell, these considerations were never explicitly assembled into a single precise definition. Our purpose in doing so is to make as explicit as possible what is involved in constructing (or in attempting to construct) optimal explanations or other representations of instructional material.

We emphasize the *structure* of the *system* of related signs. The basic insight underlying this definition is that semiotic events are not isolated phenomena, but rather occur in systems: there are common rules relating to the recognition, construction, denotation and interpretation of such a collection of signs. Moreover, semiotics as a subject is (or *should* be) more concerned with such rules than with the comparative study of individual signs and the settings in which they are found. (This distinction is like the distinction between descriptive biology and modern biology that is based on biochemistry and molecular biology.) It should be noted that this definition, like the others in this section, is set-theoretic rather than axiomatic. Thus, it avoids issues of completeness and restrictions to denumerable sets of signs, properties, functions, etc.
Definition 1: A **sign system** is a class of entities, called **signs**, divided into a set of **levels** (numbered 1 to N and not necessarily disjoint), such that signs at level n+1 (for $1 \leq n < N$) are

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[4]The way to determine the primary constructor for a given discourse type is to determine the "default" constructor for that type, i.e., the constructor that is assumed to hold when in fact there is no explicit marking in the text. For narrative, if one sentence follows another, it is assumed that they are connected by a SEQUENCE constructor; this is just the narrative presupposition.

[5]This is a limited and technical sense of "context." A broader sense has been given earlier; a still broader sense would take account of pragmatics.

constructed from signs at level n (and other signs at level n+1) by use of a fixed set of **constructor functions** (these may also have parameters and context conditions). In addition, there may be a **priority** (partial) **ordering** on these constructors at each level; and for each level, there may be predicates, relations and functions expressing properties of signs at that level. Finally, a sign system has an associated **medium** for its signs, and is **mixed** if that medium is mixed. []

We may illustrate the concepts in this definition with the system of spoken English. The underlying medium is sound, that is, acoustic signals. The signs are classed into the usual levels of spoken English, phones, phonemes, morphemes, words, phrases, sentences, and discourse units. Constructors at the sentence level are given by rules, as studied in linguistics.

Artificial systems often exhibit the structures in this definition in a very natural way. For example, let us consider a simple line-oriented editor for a standard 24 line by 80 character screen. The lowest hierarchical level is that of characters, the second that of lines, the third that of screenfulls, and the last that of sequences of screens; thus, signs at the second level consist of strings of 80 or fewer characters, and signs at the third level consist of strings of 24 or fewer lines. We can see this simple system as having just one constructor at each level greater than 1, namely STRING-OF(a1,...,aJ, J) with parameter J, which "strings together" J signs from the next lower level. The second level has the context condition $0 \leq J \leq 80$, and the third $0 \leq J \leq 24$. Since there is at most one constructor at each level, the priority ordering is trivial. However, there are some interesting predicates and functions, such as the LINE-LENGTH function for lines and the ALPHANUMERIC predicate for characters.

We can also illustrate this definition in the domain of computer graphics. Example signs include lines, characters, circles and squares. Levels might consist of pixels (individual "dots" on the screen), lines, simple figures, and windows (consisting of arbitrary "scenes," which are collections of signs at lower levels, plus other windows); each sign at each level must also have associated attributes for location on the screen, and size; there may also be attributes for color and intensity. An especially interesting constructor here is WINDOW, which can recursively encapsulate signs from all levels.

Let us now focus on our primary concern, the *translation* of signs in one system to signs in another system. It is our intention to provide the theoretical background for a general theory of the construction and interpretation of signs. For example, generating an optimal (or reasonably good) explanation, generating appropriate graphical icons, choosing a good file

name, choosing a good analogy, and understanding texts and/or graphics, can all be seen as problems of translating signs from one sign system into another. Notice that the problem of choosing an optimal mix of media also falls in this framework, since we can regard the signs in a given media mix as forming a subsystem of the total sign system within which we must choose representations. We address questions about the nature of translations between sign systems, and the reasons for preferring one translation to another, by studying maps from signs in one system to representation signs in another system.

Definition 2: Let $S1$ and $S2$ be sign systems. Then a **(semiotic) morphism** M: $S1 \rightarrow S2$, from $S1$ to $S2$, consists of the following partial functions (all denoted M):

1. Signs of $S1$ → Signs of $S2$,
2. Levels of $S1$ → Levels of $S2$,
3. Classes of $S1$ at Level i → Classes of $S2$ at Level M(i),
4. Constructors of $S1$ at Level i → Constructors of $S2$ at Level M(i), and
5. Property Predicates and Functions of $S1$ at Level i → Property Predicates and Functions of $S2$ at Level M(i),

such that

1. if $i<j$ (for $1 \leq i,j \leq N$, where N is the number of levels of $S1$) then $M(i) \leq M(j)$,
2. if r: $<c1>...<ck> \rightarrow <c>$ is a constructor at level i of $S1$, then M(r): $M(<c1>)...M(<ck>) \rightarrow M(<c>)$ is a constructor at level M(i) of $S2$ (if it is defined), and
3. if p: $<c1>...<ck>$ is a predicate at level i of $S1$, then M(p): $M(<c1>)...M(<ck>)$ is a predicate at level M(i) of $S2$ (if it is defined).

[]

Such a mapping may or may not preserve the structure of a sign system. The degree to which it does so affects the quality of its representations. A simple example of a semiotic morphism from the domain of our experimental work is the correspondance between the physical order of lights on the experimental box, and the order in which clauses are given to describe the lights (narrative order).

Our fuller exposition of this material in [Goguen & Linde 84] includes detailed definitions of what it means for a semiotic morphism M to be **level preserving**, **constructor preserving**, **priority preserving**, **property preserving**, and **structure preserving**. It is important to notice that semiotic morphisms need not be totally defined; that is, each of the functions denoted M can be undefined on some of what is in $S1$. For example, there need not be any representation in $S2$ for some signs in $S1$; in particular, some components of M could even be totally undefined, i.e., the empty function.

It seems clear that a structure preserving semiotic morphism M: $S1 \rightarrow S2$ will faithfully represent all of the semiotic structure of $S1$ in terms of that available in $S2$. This might seem to be desirable for an optimal representation; however, if the resulting structures in $S1$ are too complex, then they may be hard for human beings to understand. For example, if $S1$ consists of parse trees for English sentences and $S2$ consists of the usual "printed page" text format, then it is possible to translate all the syntactic information that is available in $S1$ into structures in $S2$ with so-called "phrase structure" notation, which uses brackets to delimit phrases and uses subscripts on brackets to indicate the class of phrase is involved. For example,

$[[[[\text{the}]_{\text{Det}}\ [\text{light}]_{\text{N}}]_{\text{NP}}[[\text{on}]_{\text{Prep}}[[\text{the}]_{\text{Det}}[\text{left}]_{\text{N}}]_{\text{NP}}]_{\text{PP}}]_{\text{NP}}[[\text{comes}]_{\text{V}}[\text{on}]_{\text{Part}}]_{\text{VP}}]_{\text{Sentence}}$

This may be useful for some purposes, but it is clearly not optimal for others. There seems to be a trade-off between the degree of structure preservation and the degree of complexity of the resulting representations.

We now turn to the complex issue of determining whether one representation (i.e., semiotic morphism) is better than another. One evident consideration is whether it preserves more structure.

Definition 3: Let M′ and M be morphisms from sign system $S1$ to sign system $S2$. Then M′ **preserves as least as much structure** as M does, provided that:

1. if M preserves a sign e at level i, then so does M′;
2. if M preserves a constructor r at signs e1,...,ek, then so does M′;
3. if M preserves a priority $r > r,'$ then so does M′; and
4. if M preserves a property p, then so does M′. []

The interesting problems arise comparing morphisms M and M′ when neither preserves strictly more structure than the other, or when one preserves more structure but also produces more complex representations. For example, M might preserve more levels than M′, whereas M′ preserves more properties than M. It is for such cases that experimental work is especially important. Our framework suggests that preserving levels is more important than preserving priorities, which is more important than preserving properties. In short, structure is more important than content.

Our experimental results suggest that the higher the level of structure, the more important it is to preserve that structure. This is an exciting, and somewhat unexpected, finding; we had originally expected a more complex ordering on levels, and had posited a basic level that was not necessarily the highest level, by analogy with work by Rosch and her students, explicating the notion of "basic level" for lexical concepts (e.g., "bird") [Rosch 73, Rosch 75]. In the case

of natural language, for the last twenty five years it has been supposed that the sentential level is basic, although more recent research is inclined to regard the discourse level as at least as important.

The body of this report described the results of testing some experimental hypotheses related to these issues. We hope that this combination of theoretical and experimental research will eventually make it possible to effectively determine of a given representation whether or not it is adequate to the task in hand. More optimistically, given sign systems $S1$ and $S2$, where $S1$ contains abstract forms of the information to be conveyed, we would like to generate (preferably automatically) a semiotic morphism M from $S1$ to $S2$ that will give adequate representations in $S2$ for signs from $S1$. For example, $S1$ might contain instructions for repairing some piece of equipment, and $S2$ might be a color graphics terminal with a speech chip and audio output. The problem is then to generate instructional material that effectively utilizes the capabilities of that particular terminal.

II. Scripts for Experimental Stimuli

Each stimulus begins with exactly the same *Task Description*, which is given here once and for all, rather than repeated fifteen times:

> Today we're going to learn how to operate this device, which is a fertilizer controller for an irrigation system. The irrigation system delivers different mixtures of water and chemicals to the fields, and this device controls which chemicals go into the water. Now your job as controller is to set up the various mixtures that your supervisor tells you are needed. And your job here today is to learn how to use this controller. There will be a test after the explanation, so please listen as carefully as you can.

II.1 Combinatorial Series Stimuli

This section presents the scripts used to produce the experimental stimuli used in the Combinatorial Series of experiments. The diagram shown in Figure 12 was used with all stimuli in this series.

II.1.1. C1 Script

This is the case of Pseudonarrative with Visual Deixis and without Structure Marking.

> *Initial Summary:*
> This fertilizer controller has two switches at the bottom, and they're numbered 1 and 2. And we'll see that there are four ways to set these two switches. Also this controller has four lights here, they're labelled A, B, C and D, and they show which chemicals are being added to the water. Now the setting of the switches controls which chemicals are added, and each chemical is represented by a light, so if I move these switches around, you see that different lights turn on and off. And because you can get four different possible settings of the switches, you can also get four different mixtures of chemicals.
>
> We have this controller with two switches and four lights and we have to learn how to operate it. Let's make sure that there really are just four possible ways to set these two switches. We'll start with the first setting, which has both switches up. Then we go to the second setting, which has both switches down. Then we go to the third setting, which has the first switch up and the second switch down. Finally, we go to the fourth setting, which has the first switch down and the second switch up. And that's all the settings that there are. This fertilizer controller can only select among four mixtures of chemicals to add to the water.
>
> Each of these switch settings has its own pattern of lights, that is, some of the lights are on and others are off when the switches are set that way. Let's start with the setting where we put both switches up. That gives us lights A, C, and D. Next, let's

put both switches down. That gives us lights A, B, and D. Then we can put switch 1 up and switch 2 down and that gives us no lights on at all. Finally we can put switch 1 down and switch 2 up and that gives us the lights A and C.

Let's use this diagram. The top indicates the four lights, for the four chemicals, and the left side shows the four switch settings. So first we have 1 up and 2 up and we get lights A, C, and D. Next we go to both down and that gives us A, B and D. Then we go to 1 up and 2 down and we get no lights at all. And finally we go to 1 down and 2 up and that gives us A and C.

Suppose that your supervisor wants you to get a particular mixture of chemicals. For example, maybe she wants to get the mixture A, C, D. Then all you have to do is look at the diagram and see which switch setting produces that mixture. So, the first line shows us that both switches up produces the mixture she wants.

Another thing that the supervisor might want is just any setting that will give the chemical indicated by light D. Looking at the diagram, we can see that if either Switch 1 and Switch 2 are both up, or else if Switch 1 and Switch 2 are both down, we will get some of the chemical indicated by light D.

Final Summary:
The way this controller works is that the four lights indicate the chemicals and the different patterns of lights depend on the settings of the two switches. So if you want to get a particular mixture of chemicals, you have to know which switch setting gives that mixture. And if you want to know how to get a particular chemical, you have to know which switch settings give it.

II.1.2. C2 Script

This is the case of Pseudonarrative without Visual Deixis and without Structure Marking. The text is identical to that of C1, but the actor did not employ Visual Deixis.

II.1.3. C3 Script

This is the case of Pseudonarrative with Visual Deixis and with Structure Marking.

Initial Summary:
So as you can see, this fertilizer controller has two switches at the bottom, and they're numbered 1 and 2. And we'll see that there are four ways to set these two switches. Also this controller has four lights here, they're labelled A, B, C and D, and they show which chemicals are being added to the water. Now the setting of the switches controls which chemicals are added, and each chemical is represented by a light, so if I move these switches around, you see that different lights turn on and off. And because you can get four different possible settings of the switches, you can also get four different mixtures of chemicals.

So to begin, we have this controller with two switches and four lights and we have to learn how to operate it. Now let's make sure that there really are just four possible ways to set these two switches. *Go through the four positions on the box.* We'll start with the first setting, which has both switches up. Then we go to the second setting, which has both switches down. Then we go to the third setting, which has the first switch up and the second switch down. Finally, we go to the fourth setting, which has the first switch down and the second switch up. And that's all the settings that there are. So this fertilizer controller can only select among four mixtures of chemicals to add to the water.

Now each of these switch settings has its own pattern of lights, that is, some of the lights are on and others are off when the switches are set that way. Let's start with the setting where we put both switches up. That gives us lights A, C, and D. Next, let's put both switches down. That gives us lights A, B, and D. Then we can put switch 1 up and switch 2 down and that gives us no lights on at all. Finally we can put switch 1 down and switch 2 up and that gives us the lights A and C.

Now let's go over this again and use this diagram. The top indicates the four lights, for the four chemicals, and the left side shows the four switch settings. So first we have 1 up and 2 up and we get lights A, C, and D. Next we go to both down and that gives us A, B and D. Then we go to 1 up and 2 down and we get no lights at all. And finally we go to 1 down and 2 up and that gives us A and C. And this diagram shows us all of this.

Now suppose that your supervisor wants you to get a particular mixture of chemicals. For example, maybe she wants to get the mixture A, C, D. Then all you have to do is look at the diagram and see which switch setting produces that mixture. So, the first line shows us that both switches up procduces the mixture she wants.

Another thing that the supervisor might want is just any setting that will give the chemical indicated by light D. Looking at the diagram, we can see that if either Switch 1 and Switch 2 are both up, or else if Switch 1 and Switch 2 are both down, we will get some of the chemical indicated by light D.

Final Summary:
So as you've seen, the way this controller works is that the four lights indicate the chemicals and the different patterns of lights depend on the settings of the two switches. So if you want to get a particular mixture of chemicals, you have to know which switch setting gives that mixture. And if you want to know how to get a particular chemical, you have to know which switch settings give it.

II.1.4. C4 Script

This is the case of Pseudonarrative without Visual Deixis and with Structure Marking. The text is identical to that of C3, but the actor did not use Visual Deixis.

II.1.5. C5 Script

This is the case of Reasoning with Visual Deixis and without Structure Marking.

Initial Summary:
This fertilizer controller has two switches at the bottom, and they're numbered 1 and 2. And we'll see that there are four ways to set these two switches. Also this controller has four lights up here, they're labelled A, B, C and D, and they show which chemicals are being added to the water. Now the setting of the switches controls which chemicals are added, and each chemical is represented by a light, so if I move these switches around, you see that different lights turn on and off. And because you can get four different settings of the switches, you can also get four different mixtures of chemicals.

Here is this controller with two switches and four lights and your job is to learn how to operate it. First, let's make sure that there really are just four ways to set these switches. Each switch has exactly two settings, up and down. So if 1 is up, then 2 could be up or 2 could be down, and that's two settings. Now Switch 1 could be changed to down, and then still 2 could be up or down. So that's another two settings, and which makes four settings altogether. So this fertilizer controller can only select among four mixtures of chemicals to add to the water.

Each of these switch settings has its own pattern of lights, that is, some of the lights are on and others are off when the switches are set that way. For the first setting, where both switches are up, we have lights A, C and D on. And for the second setting, where both switches are down, lights A, B, and D are on. For the third setting, with switch 1 up and switch 2 down, we get no lights on at all. And for the last setting, with 1 down and 2 up, we see that only lights A and C are on. That's all four cases.

This diagram summarizes everything that we said before. The top indicates the four lights, for the four chemicals, and the left side shows the four different switch settings. So first both 1 and 2 are up, and that has A, C, and D on. Next, both 1 and 2 are down, and that has A B and D on. Then 1 is up and 2 is down, and that has no lights on at all. And finally, 1 is down and 2 is up, and that has A, and C on.

Now suppose that your supervisor wants you to get a particular mixture of chemicals. For example, maybe she wants to get the mixture A, C, D. Then all you have to do is look at the diagram and see which switch setting gives that mixture. So, the first line shows us that both switches up gives the mixture she wants.

Another thing that the supervisor might want is just any setting that will give the chemical indicated by light D. Looking at the diagram, we can see that if either Switch 1 and Switch 2 are both up, or else if Switch 1 and Switch 2 are both down, we get some of the chemical indicated by light D.

Final Summary:
The way this controller works is that the four lights depend on the settings of the two switches, and the different patterns of lights depend on the settings of the switches. So if you want to get a particular mixture of chemicals, you have to know which switch settings give it.

II.1.6. C6 Script

This is the case of Reasoning without Visual Deixis and without Structure Marking. The text is identical to that of C5, but the actor does not use Visual Deixis.

II.1.7. C7 Script

This is the case of Reasoning with Visual Deixis and with Structure Marking.

Initial Summary:
So as you can see, this fertilizer controller has two switches at the bottom, and they're numbered 1 and 2. And we'll see that there are four ways to set these two switches. Also this controller has four lights up here, they're labelled A, B, C and D, and they show which chemicals are being added to the water. Now the setting of the switches controls which chemicals are added, and each chemical is represented by a light, so if I move these switches around, you see that different lights turn on and off. And because you can get four different settings of the switches, you can also get four different mixtures of chemicals.

So to begin, here is this controller with two switches and four lights and your job is to learn how to operate it. First, let's make sure that there really are just four ways to set these switches. Each switch has exactly two settings, up and down. So if 1 is up, then 2 could be up or 2 could be down, and that's two settings. Now Switch 1 could be changed to down, and then still 2 could be up or down. So that's another two settings, and which makes four settings altogether. So this fertilizer controller can only select among four mixtures of chemicals to add to the water.

Now each of these switch settings has its own pattern of lights, that is, some of the lights are on and others are off when the switches are set that way. So for the first setting, where both switches are up, we have lights A, C and D on. And for the second setting, where both switches are down, lights A, B, and D are on. For the third setting, with switch 1 up and switch 2 down, we get no lights on at all. And for the last setting, with 1 down and 2 up, we see that only lights A and C are on. So that's all four cases.

Now this diagram summarizes everything that we said before. The top indicates the four lights, for the four chemicals, and the left side shows the four different switch settings. So first both 1 and 2 are up, and that has A, C, and D on. Next, both 1 and 2 are down, and that has A B and D on. Then 1 is up and 2 is down, and that has no lights on at all. And finally, 1 is down and 2 is up, and that has A and C on. So this diagram shows us all of this.

Now suppose that your supervisor wants you to get a particular mixture of chemicals. For example, maybe she wants to get the mixture A, C, D. Then all you have to do is look at the diagram and see which switch setting gives that mixture. So, the first line shows us that both switches up gives the mixture she wants.

Another thing that the supervisor might want is just any setting that will give the chemical indicated by light D. Looking at the diagram, we can see that if either Switch 1 and Switch 2 are both up, or else if Switch 1 and Switch 2 are both down, we get some of the chemical indicated by light D.

Final Summary:
So as you've seen, the way this controller works is that the four lights depend on the settings of the two switches, and the different patterns of lights depends on the settings of the switches. So if you want to get a particular mixture of chemicals, you have to know which switch settings give it.

II.1.8. C8 Script

This is the case of Reasoning without Visual Deixis and with Structure Marking. The text is identical to that of C7, but the actor does not use Visual Deixis.

II.2 Boolean Level Stimuli

This section gives the scripts used in producing the experimental stimuli for the B Series Experiments. All these stimuli emply Reasoning at the Boolean cognitive level. A diagram consisting of the equations mentioned in the text was used for all stimuli except B7 (see Figure II-1).

```
C = Sw2
X = ~Sw2
Y = Sw1 AND Sw2
B = ~Sw1 AND ~Sw2
Z = Sw1 oR sw2
D = (Sw1 AND Sw2) OR (~Sw1 AND ~Sw2)
A = (Sw1 AND Sw2) OR ~Sw1
```

Figure II-1: B Series Diagram

II.2.1. B1 Script

This is the basic case of Reasoning Structure at the Boolean cognitive level.

Initial Summary:

Right now this controller only gives certain particular mixtures of chemicals and water. But actually, it can be programmed, so that the same switch settings produce different mixtures. Now when you're controlling the system, you may have to figure out which switch settings produce a certain chemical. Then it will help a lot if you have a simple description of when each chemical is present. The easiest way to get these descriptions is to use some concepts from logic, like AND, OR, and NOT. Now what I'm going to do, is describe how this box works, and then describe how you can use these concepts to figure out how to get the mixture of chemicals that your supervisor wants.

So as you can see, this fertilizer controller has two switches at the bottom, and they're numbered 1 and 2. And we'll see that there are four ways to set these two switches. Also this controller has four lights up here, they're labelled A, B, C and D, and they show which chemicals are being added to the water. Now the setting of the switches controls which chemicals are added, and each chemical is represented by a light, so as I move these switches around, you can see that different lights turn off and on. And because you can get four different settings of the switches, you can also have four different combinations of chemicals.

You might think you can just memorize what happens for each switch setting. But the box is programmable, so even if you memorize one way that the box might work, there are a lot of other ways that you won't know about, and there are too many possibilities to memorize them all. So it would really help if we could just work with simple descriptions for all the ways in a particular program that a given light could be on. This is what we're going to use formal descriptions for. Now we'll go through each of the lights, showing how to describe which switch settings turn them on.

The simplest case is light C, which is on when switch 2 is up, no matter how switch 1 is set, and off when switch 2 is down, no matter how switch 1 is set. We can express this by saying "C equals switch 2".

$$C = Sw2$$

Now when we say "Sw2" here, it just means that "switch 2 is on."

If some light, let's call it X, worked just the opposite from light C, that is, if it were on when switch 2 is down and off when switch 2 is up, no matter how switch 1 is set, we would say "X equals NOT Sw2".

$$X = \sim Sw2$$

That is, "not" means to take the opposite of whatever the value is.

To describe more complicated relations, we also need AND. We could have a light, call it Y, that is on if both switch 1 and switch 2 are up, and is off otherwise. Then we would say "Y equals switch 1 AND switch 2".

Y = Sw1 AND Sw2 .

Now this particular program for the box doesn't have a light like Y, but light B is only on when both switches are down. So we can say "B equals NOT Switch 1 AND NOT Switch 2".

B = ~Sw1 AND ~Sw2 .

We also need OR. In this kind of formal description, OR is a bit different from the way we use it in English. If we have a light described by "Z equals Switch 1 OR Switch 2",

Z = Sw1 OR Sw2

then light Z is on if either switch 1 is up, or if switch 2 is up, or if both switches are up. And Z is off in all other cases. We'll use this kind of OR when we describe how lights D and A work. But first, notice that we can use combinations of AND, OR and NOT to form more complicated descriptions. For example, the description that we gave for B combines two NOTs with an AND.

Now let's describe light D. It is on when both switches have the same setting. This means that either both switches are up OR both switches are down. We can describe this as "D equals Switch 1 AND Switch 2 OR (*pause*) NOT Switch 1 AND NOT Switch 2".

D = (Sw1 AND Sw2) OR (~Sw1 AND ~Sw2) .

Finally, let's describe light A, which may seem to be the most difficult case. A is on if both switches are up, or if switch 1 is down, no matter where 2 is, and is off in all other cases. We can describe this as "A equals Switch 1 AND Switch 2 OR (*pause*) NOT Switch 1".

A= (Sw1 AND Sw2) OR ~Sw1 .

Now suppose that your supervisor wants you to get the chemical indicated by light B. Looking at the description for B, we can see that B is on only if both Switch 1 and Switch 2 are both down. (But if she asks for some other chemical, there may be more than one setting of switches that will work.)

Another thing your supervisor might want is to get a particular mixture of chemicals. For example, she might want to get the mixture A, B, D. Now the description for A will tell you which switch settings have A on, and then you can look at the description for B to see which settings for A also have B on, and finally use the description for D to see which of these have D on too. Actually, it would be easier to start with B, since we now know there is only one setting where B is on, and then you can just see if A and D are also on when Switch 1 and Switch 2 are both up.

Final Summary:

So as you've seen, the way this controller works is that the four lights indicate the chemicals and the different patterns of lights depend on the settings of the two

switches. So if you want to get a particular mixture of chemicals, you have to know which switch setting gives that mixture. And if you want to know how to get a particular chemical, you have to know which switch settings give it. And an easy way to express the various possible switch settings is to use these concepts of AND, OR, and NOT from logic.

II.2.2. B2 Script

This is the case of Boolean level Reasoning, without an initial summary. The text is identical to that of B1, except that the initial summary is replaced by the following filler proposition:

> So, as you can see, we have here an irrigation controller, which controls the process of adding chemicals to the water that goes out to irrigate the different crops in various fields. Different kinds of crops need different mixtures of fertilizers to help them reach their optimum growth, so the operator of the controller has to be able to change the mixture of chemicals, depending on what crops are being grown, what the temperature is, how much sunlight there is, how much rain there is, and so on. And the operator of the controller device would make the changes when he or she received orders by telephone from a supervisor who had more information about the whole system.

The length of this is approximately equal to that of the original initial summary.

II.2.3. B3 Script

This is the case of Reasoning Structure without a final summary. The text is identical to that of B1, except that the final summary is replaced by the following filler proposition:

> So if you were to get this job working as the operator of an irriguation control system, that's what your job would be. Of course, we've gone over only part of the job. You would also be monitoring other devices as well, checking that many other irrigation systems were functioning correctly, that there were no blockages in the lines, or breaks or leaks in the system, and that the chemicals were flowing correctly, and so on.

The length of this is approximately equal to that of the original final summary.

II.2.4. B4 Script

This is the case Boolean level Reasoning with sentential focus inconsistencies.

> *Initial Summary:*
> Right now this controller only gives certain particular mixtures of chemicals and water. But actually, it can be programmed, so that the same switch settings produce different mixtures. Now, you may have to figure out how to produce a certain chemical when you're controlling the system. Then it will help a lot if you have a simple description of which switch settings produce that chemical. The easiest way to get these descriptions is to use some concepts from logic, like AND, OR, and NOT.

Now what I'm going to do, is describe how this box works, and then describe how you can use these concepts to get the mixture of chemicals that your supervisor wants.

So as you can see, this fertilizer controller has two switches at the bottom, and also four lights up here. Now the switches are numbered 1 and 2, and the lights are labelled A, B, C and D. And we will see that there are four ways to set the two switches. Now the lights show which chemicals are being added to the water. And the setting of the switches controls which chemicals are added. Now each chemical is represented by a light. So, as I move these switches around, you can see that different lights turn off and on. And so you can get four different combinations of chemicals, because there are just four different settings of the switches.

You might think you can just memorize what happens for each switch setting. But the box is programmable, so even if you memorize one way that the box might work, there are a lot of other ways that you won't know about, and there are too many possibilities to memorize them all. So it would really help if we could just work with simple descriptions for all the ways in a particular program that a given light could be on. This is what we're going to use formal descriptions for. Now we'll go through the different cases and show how different switch settings give different lights.

The simplest case is light C. Now when switch 2 is up, then light C is on, no matter how switch 1 is set. And light C is off when switch 2 is down, no matter how switch 1 is set. We can express this by saying "C equals switch 2",

C = Sw2

Now when we say "Sw2" here, it just means that "switch 2 is on."

We might have a light, let's call it X, that worked just the opposite from light C. That is, when switch 2 is down X would be on, and it would be off when switch 2 is up, no matter how switch 1 is set. Then we would say "X equals NOT Sw2".

X = ~Sw2

That is, "not" means to take the opposite of whatever the value is.

To describe more complicated relations, we also need AND. So let's imagine another light, call it Y, and say that if both switch 1 and switch 2 are up, then Y is on, and otherwise it is off. Then we would say "Y equals switch 1 AND switch 2".

Y = Sw1 AND Sw2 .

Now this particular program for the box doesn't have a light like Y, but only when both switches are down can we have light B on. So we can say "B equals NOT Switch 1 AND NOT Switch 2".

B = ~Sw1 AND ~Sw2 .

We also need OR. In this kind of formal description, OR is a bit different from the way we use it in English. We might have a light described by "Z equals Switch 1 OR Switch 2",

Z = Sw1 OR Sw2 .

So if either switch 1 is up, or if switch 2 is up, or if both switches are up, then light Z is on. And Z is off in all other cases. We'll use this kind of OR when we describe how lights D and A work. But first, notice that we can use combinations of AND, OR and NOT to form more complicated descriptions. For example, the description that we gave for B combines two NOTs with an AND.

Now let's describe light D. When both switches have the same setting, then D is on. This means D is on if either both switches are up OR both switches are down. We can describe this as "D equals Switch 1 AND Switch 2 OR (*pause*) NOT Switch 1 AND NOT Switch 2".

D = (Sw1 AND Sw2) OR (~Sw1 AND ~Sw2) .

Finally, let's describe light A, which may seem to be the most difficult case. If both switches are up then A is on, OR it is on if switch 1 is down, no matter where 2 is, and in all other cases A is off. We can describe this as "A equals Switch 1 AND Switch 2 OR (*pause*) NOT Switch 1".

A= (Sw1 AND Sw2) OR ~Sw1 .

Now suppose that your supervisor wants you to get the chemical indicated by light B. We can see that only both Switch 1 and Switch 2 down gives light B on, from the description of B. (But if she asks for some other chemical, there may be more than one setting of switches that will work.)

Another thing your supervisor might want is to get the switch settings for a particular mixture of chemicals. For example, she might want to get the mixture A, B, D. Now you can find which switch settings have A on from the description of A, and then you can look at the description of B to see which settings for A also have B on, and finally you can get the switch settings for D from its description and see which of these have A and B on too. Actually, it would be easier to start with B, since we now know there is only one setting where B is on, and then you can just see if A and D are also on when Switch 1 and Switch 2 are both up.

Final Summary:

So as you've seen, the way this controller works is that the four lights indicate the chemicals, and the different settings of the two switches produce different patterns of lights. So if you want to get a particular mixture of chemicals, you have to know which switch setting gives that mixture. And if you know which switch settings give a particular chemical, you can get that chemical with them. So an easy way to express the various possible switch settings is to use these concepts of AND, OR, and NOT from logic.

II.2.5. B5 Script

This is the case of Boolean level Reasoning with discourse subunit boundary violations.

Initial Summary:
Right now this controller only gives certain particular mixtures of chemicals and water. And when you're controlling the system, you may have to figure out which switch settings produce a certain chemical. Then it will help a lot if you have a simple description of when each chemical is present. The easiest way to get these descriptions is to use some concepts from logic, like AND, OR, and NOT. This is because the controller can be programmed, so that the same switch settings produce different mixtures in other programs.

So as you can see, this fertilizer controller has two switches at the bottom, and they're numbered 1 and 2. Now what I'm going to do, is describe how this box works, and then describe how you can use these concepts from logic to figure out how to get the mixture of chemicals that your supervisor wants. And we'll see that there are four ways to set these two switches. Now the setting of the switches controls which chemicals are added, and each chemical is represented by a light, so as I move these switches around, you can see that different lights turn off and on. Also this controller has four lights up here, they're labelled A, B, C and D, and they show which chemicals are being added to the water.

Now because you can get four different settings of the switches, you can also have four different combinations of chemicals. You might think you can just memorize what happens for each switch setting. But the box is programmable, so even if you memorize one way that the box might work, there are a lot of other ways that you won't know about. And because there are too many possibilities to memorize them all, it would really help if we could just work with simple descriptions for all the ways in a particular program that a given light could be on. This is what we're going to use formal descriptions for.

The simplest case is light C. What we're doing now is going through each of the lights, showing how to describe which switch settings turn them on. So C is on when switch 2 is up, no matter how switch 1 is set, and off when switch 2 is down, no matter how switch 1 is set. Now when we say "Sw2," we just mean that "switch 2 is on", then we can describe when light C is on by saying "C equals switch 2".

$$C = Sw2 .$$

Imagine a light, let's call it X, that is on when switch 2 is down and off when switch 2 is up, no matter how switch 1 is set. Then X works just the opposite from light C. And if we let "NOT" mean to take the opposite of whatever the value is, then we can say "X equals NOT Sw2".

$$X = \sim Sw2 .$$

We could also have a light, call it Y, that is on if both switch 1 and switch 2 are up,

and is off otherwise. We need AND to describe relations like this. For example, we would say "Y equals switch 1 AND switch 2".

Y = Sw1 AND Sw2 .

Now light B is only on when both switches are down, so it is only a little different from light Y. It can be described by saying "B equals NOT Switch 1 AND NOT Switch 2".

B = ~Sw1 AND ~Sw2 .

Also imagine a light described by "Z equals Switch 1 OR Switch 2".

Z = Sw1 OR Sw2 .

In this kind of formal description, OR is a bit different from the way we use it in English, since light Z is on if either switch 1 is up, or if switch 2 is up, or if both switches are up. And Z is off in all other cases.

Notice that we can use combinations of AND, OR and NOT to form more complicated descriptions. For example, the description that we gave for B combines two NOTs with an AND. We'll also use this kind of OR when we describe how lights D and A work.

Now let's describe light D. It is on when both switches have the same setting. This means that either both switches are up OR both switches are down. We can describe this as "D equals Switch 1 AND Switch 2 OR (*pause*) NOT Switch 1 AND NOT Switch 2".

D = (Sw1 AND Sw2) OR (~Sw1 AND ~Sw2) .

Finally, let's describe light A. It is on if both switches are up, or if switch 1 is down, no matter where 2 is, and is off in all other cases. We can describe this as "A equals Switch 1 AND Switch 2 OR (*pause*) NOT Switch 1".

A= (Sw1 AND Sw2) OR ~Sw1 .

This may seem to be the most difficult case.

Now suppose that your supervisor wants you to get the chemical indicated by light B. If she asks for some other chemical, there may be more than one setting of switches that will work, but looking at the description for B, we can see that B is on only if Switch 1 and Switch 2 are both down.

Another thing your supervisor might want is to get a particular mixture of chemicals. Then you can use the descriptions to see which settings work. Thus, the description for A will tell you which switch settings have A on. Suppose your supervisor wants to get the mixture A, B, D. Then you can look at the description for B to see which settings for A also have B on, and finally use the description for D to see which of these have D on too. Actually, it would be easier to start with B, since we now know there is only one setting where B is on, and then you can just see if A and D are also on when Switch 1 and Switch 2 are both down.

Final Summary:
So as you've seen, the way this controller works is that the four lights indicate the chemicals. So if you want to get a particular mixture of chemicals, you have to know which switch setting gives that mixture, because the different patterns of lights depend on the settings of the two switches. And if you want to know how to get a particular chemical, you have to know which switch settings give it. And an easy way to express the various possible switch settings is to use these concepts of AND, OR, and NOT from logic.

II.2.6. B6 Script

This is the case of Boolean level Reasoning with discourse subunits in a scrambled order.

So as you can see, this fertilizer controller has two switches at the bottom, and they're numbered 1 and 2. And we'll see that there are four ways to set these two switches. Also this controller has four lights up here, they're labelled A, B, C and D, and they show which chemicals are being added to the water. Now the setting of the switches controls which chemicals are added, and each chemical is represented by a light, so as I move these switches around, you can see that different lights turn off and on. And because you can get four different settings of the switches, you can also have four different combinations of chemicals.

The simplest case is light C, which is on when switch 2 is up, no matter how switch 1 is set, and off when switch 2 is down, no matter how switch 1 is set. We can express this by saying "C equals switch 2".

$C = Sw2$

Now when we say "Sw2" here, it just means that "switch 2 is on."

If some light, let's call it X, worked just the opposite from light C, that is, if it were on when switch 2 is down and off when switch 2 is up, no matter how switch 1 is set, we would say "X equals NOT Sw2".

$X = \sim Sw2$

That is, "not" means to take the opposite of whatever the value is.

Initial Summary:
Right now this controller only gives certain particular mixtures of chemicals and water. But actually, it can be programmed, so that the same switch settings produce different mixtures. Now when you're controlling the system, you may have to figure out which switch settings produce a certain chemical. Then it will help a lot if you have a simple description of when each chemical is present. The easiest way to get these descriptions is to use some concepts from logic, like AND, OR, and NOT. Now what I'm going to do, is describe how this box works, and then describe how you can use these concepts to figure out how to get the mixture of chemicals that your supervisor wants.

To describe more complicated relations, we also need AND. We could have a light,

call it Y, that is on if both switch 1 and switch 2 are up, and is off otherwise. Then we would say "Y equals switch 1 AND switch 2".

Y = Sw1 AND Sw2 .

Now this particular program for the box doesn't have a light like Y, but light B is only on when both switches are down. So we can say "B equals NOT Switch 1 AND NOT Switch 2".

B = ~Sw1 AND ~Sw2 .

We also need OR. In this kind of formal description, OR is a bit different from the way we use it in English. If we have a light described by "Z equals Switch 1 OR Switch 2",

Z = Sw1 OR Sw2

then light Z is on if either switch 1 is up, or if switch 2 is up, or if both switches are up. And Z is off in all other cases. We'll use this kind of OR when we describe how lights D and A work. But first, notice that we can use combinations of AND, OR and NOT to form more complicated descriptions. For example, the description that we gave for B combines two NOTs with an AND.

You might think you can just memorize what happens for each switch setting. But the box is programmable, so even if you memorize one way that the box might work, there are a lot of other ways that you won't know about, and there are too many possibilities to memorize them all. So it would really help if we could just work with simple descriptions for all the ways in a particular program that a given light could be on. This is what we're going to use formal descriptions for. Now we'll go through each of the lights, showing how to describe which switch settings turn them on.

Final Summary:
So as you've seen, the way this controller works is that the four lights indicate the chemicals and the different patterns of lights depend on the settings of the two switches. So if you want to get a particular mixture of chemicals, you have to know which switch setting gives that mixture. And if you want to know how to get a particular chemical, you have to know which switch settings give it. And an easy way to express the various possible switch settings is to use these concepts of AND, OR, and NOT from logic.

Now suppose that your supervisor wants you to get the chemical indicated by light B. Looking at the description for B, we can see that B is on only if Switch 1 and Switch 2 are both down. (But if she asks for some other chemical, there may be more than one setting of switches that will work.)

Another thing your supervisor might want is to get a particular mixture of chemicals. For example, she might want to get the mixture A, B, D. Now the description for A will tell you which switch settings have A on, and then you can look at the description for B to see which settings for A also have B on, and finally use the

description for D to see which of these have D on too. Actually, it would be easier to start with B, since we now know there is only one setting where B is on, and then you can just see if A and D are also on when Switch 1 and Switch 2 are both up.

Now let's describe light D. It is on when both switches have the same setting. This means that either both switches are up OR both switches are down. We can describe this as "D equals Switch 1 AND Switch 2 OR (*pause*) NOT Switch 1 AND NOT Switch 2".

D = (Sw1 AND Sw2) OR (~Sw1 AND ~Sw2) .

Finally, let's describe light A, which may seem to be the most difficult case. A is on if both switches are up, or if switch 1 is down, no matter where 2 is, and is off in all other cases. We can describe this as "A equals Switch 1 AND Switch 2 OR (*pause*) NOT Switch 1".

A= (Sw1 AND Sw2) OR ~Sw1 .

II.2.7. B7 Script

This is the case of Boolean level Reasoning with a diagram that is not coordinated with the text. The text is identical to that of B1, but Figure 12 is used instead of Figure II-1.

III. Test Questions

This appendix contains the questionaires whose scores are used as dependent variables for the C and B Series of stimuli.

III.1 Combinatorial Series Questions

1. How many mixtures that contain chemical A can you get with this controller?
2. Which switch settings produce pure water? (Check all the applicable switch settings.)
3. Can you get fertilized water consisting of the mixture A, C, D of chemicals?
4. Can you get fertilized water consisting of exactly the mixture A, D of chemicals?
5. How many different switch settings yield either chemical B or else the chemicals A and C?
6. Does any switch setting produce water containing all the chemicals?
7. How many mixtures that contain both chemicals A and C can you get with this controller?
8. How many different mixtures of fertilized or unfertilized water does this controller produce?
9. How many different switch settings contain either chemical D or else the chemicals A and C?
10. Do previous switch settings have any effect on the result of a switch setting?
11. Do the following describe the same switch settings?
    a. Sw1 and Sw2 are the same.
    b. Sw1 and Sw2 are both up or else Sw1 and Sw2 are both down.
12. Do the following describe the same switch settings?
    a. Either Sw1 is up or else both Sw1 and Sw2 are down.
    b. Either Sw2 is down or Sw1 is up.
13. Do the following describe the same switch settings?
    a. Either Sw2 is up or else Sw1 is down.
    b. Either Sw1 and Sw2 are up or else Sw1 is down.

(Question 5 was not used in computing C Series scores, since its entry on the answer sheet was flawed.)

III.2 Boolean Series Questions

1. How many mixtures that contain chemical A can you get with this controller?
2. Which switch settings produce pure water? (Check all the applicable switch settings.)
3. Can you get fertilized water consisting of exactly the mixture A, C, D of chemicals?

4. Can you get fertilized water consisting of exactly the mixture A, D of chemicals?
5. How many different switch settings yield either chemical B or else the chemicals A and C?
6. Does any switch setting produce water containing all the chemicals?
7. How many mixtures that contain both chemicals A and C can you get with this controller?
8. What is the maximum number of different kinds of fertilized water that the controller can produce?
9. Do previous switch settings have any effect on the result of a switch setting?
10. Is it necessary to always have one switch setting that produces pure water?
11. Do 1 and 2 describe the same switch settings?
    a. Sw1 AND Sw2 .
    b. ~Sw1 OR ~Sw2 .
12. Do 1 and 2 describe the same switch settings?
    a. Sw1 OR (~Sw1 AND ~Sw2) .
    b. ~Sw2 OR Sw1 .
13. Do 1 and 2 describe the same switch settings?
    a. ~(Sw1 OR Sw2) .
    b. ~Sw1 AND ~Sw2 .
14. Do 1 and 2 describe the same switch settings?
    a. Sw1 AND (Sw1 OR Sw2) .
    b. Sw1 AND Sw2 .
15. Do 1 and 2 describe the same switch settings?
    a. Sw1 AND ~Sw2 .
    b. ~Sw1 OR Sw2 .
16. Do 1 and 2 describe the same switch settings?
    a. ~Sw1 AND ~Sw2 .
    b. Sw1 OR Sw2 .

IV. Papers in Preparation

Three papers are in preparation reflecting results produced under sponsorship of this project:

1. "The Effect of Discourse Type on Comprehension", by Joseph Goguen and Charlotte Linde. This paper will present our findings on the C Series experiments.
2. "Visual Deixis", by Charlotte Linde and Joseph Goguen. This paper will present our results on visual deixis.
3. "Foundations of Semiotics," by Joseph A. Goguen, Tora Bikson and Charlotte Linde. This paper will present our mathematical theory of semiotic structure, emphasizing its applications to multi-media instruction.

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